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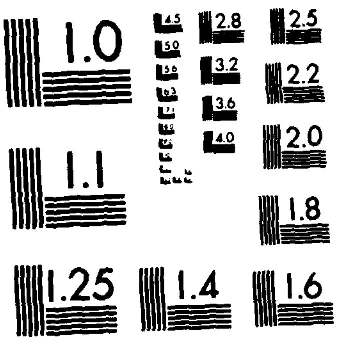

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THESIS

CHARACTERISTICS OF A FLUTED
NOZZLE GAS EDUCTOR SYSTEM

by

Jerry Wayne Boykin

March 1983

Thesis Advisor: P. F. Pucci

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. A128 065
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Characteristics of a Fluted Nozzle Gas Eductor System	5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; March 1983
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jerry Wayne Boykin	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	12. REPORT DATE March 1983
	13. NUMBER OF PAGES 226
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Mixing Stack
Fluted Nozzles
Pumping Coefficient

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Cold flow tests were conducted on a four nozzle and a one nozzle gas eductor system. The nozzles employed were fluted with a constant cross sectional area. The four nozzle tests used a mixing stack length-to-diameter ratio, (L/D), of 1.5; the single nozzle tests used L/D ratios of 2.0, 1.75 and 1.5. The total cross sectional area of the four fluted nozzles to the cross sectional area of the mixing stack was 2.5; for

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S/N 0102-014-6601

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the single fluted nozzle, 2.42. Secondary pumping coefficients, mixing stack pressure distributions and exit velocity profiles were determined.

The pumping performance of the four fluted nozzle system was found to be comparable to a straight nozzle system, showing no specific advantages. The single fluted nozzle system pumping performance showed a slight improvement with increased L/D. The system performance was comparable to the four straight nozzle system at the same L/D. The peak exit velocities of the single fluted nozzle system were higher than those for the four straight and four fluted nozzle systems.

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Characteristics of a Fluted Nozzle Gas Eductor System

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Cold flow tests were conducted on a four nozzle and a one nozzle gas eductor system. The nozzles employed were fluted with a constant cross sectional area. The four nozzle tests used a mixing stack length-to-diameter ratio, (L/D), of 1.5; the single nozzle tests used L/D ratios of 2.0, 1.75 and 1.5. The total cross sectional area of the four fluted nozzles to the cross sectional area of the mixing stack was 2.5; for the single fluted nozzle, 2.42. Secondary pumping coefficients, mixing stack pressure distributions, and exit velocity profiles were determined.

The pumping performance of the four fluted nozzle system was found to be comparable to a straight nozzle system, showing no specific advantages. The single fluted nozzle system pumping performance showed a slight improvement with increased L/D. The system performance was comparable to the four straight nozzle system at the same L/D. The peak exit velocities of the single fluted nozzle system were higher than those for the four straight and four fluted nozzle systems.

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NOMENCLATURE

<u>English Letter Symbols</u>

A	Area (in.^{2})
c	Sonic velocity (ft/sec)
C	Coefficient of discharge
D	Diameter (in.)
F_a	Thermal expansion factor
F_{fr}	Wall skin-friction force (lbf)
g_c	Proportionality factor in Newton's Second Law (g_c = 32.174 lbm-ft/lbf-sec^2)
h	Enthalpy (Btu/lbm)
k	Ratio of specific heats
L	Length (in.)
P	Pressure (in. H_2O)
P_a	Atmospheric pressure (in. Hg)
P_v	Velocity head (in. H_2O)
PMS	Static pressure along the length of the mixing stack (in. H_2O)
R	Gas constant for air (R = 53.34 ft-lbf/lbm-R)
s	Entropy (Btu/lbm-R)
S	Distance from primary nozzle exit plane to mixing stack entrance plane (in.)
T	Absolute temperature (R)

u	Internal energy (Btu/lbm)
U	Velocity (ft/sec)
v	Specific volume (ft^3/lbm)
W	Mass flow rate (lbm/sec)
Y	Expansion factor

<u>Dimensionless Groupings</u>

A*	Ratio of secondary flow area to primary flow area
AR	Area ratio
f	Friction factor
K	Flow coefficient
K_e	Kinetic energy correction factor
K_m	Momentum correction factor at the mixing stack exit
K_p	Momentum correction factor at the primary nozzle exit
L/D	Ratio of mixing stack length to mixing stack diameter
M	Mach number
P*	Pressure coefficient
PMS*	Mixing stack pressure coefficient
Re	Reynolds number
S/D	Standoff; ratio of distance from primary nozzle exit plane to entrance plane of the mixing stack (S) to the diameter of the mixing stack (D)
T*	Absolute temperature ratio of the secondary flow to primary flow

T_t^* , TT*	Absolute temperature ratio of the tertiary flow to primary flow
W_s^* , W*	Secondary mass flow rate to primary mass flow rate ratio
W_t^* , WT*	Tertiary mass flow to primary mass flow rate ratio
ρ^*	Induced flow density to primary flow density ratio

Greek Letter Symbols

μ	Absolute viscosity (lbf-sec/ft^2)
ρ	Density (lbm/ft^3)
θ	Primary nozzle tilt angle
ϕ	Primary nozzle rotation angle
ψ	Nozzle base plate rotation angle
β	Ratio of ASME long radius metering nozzle throat diameter to inlet diameter

Subscripts

0	Section within secondary air plenum
1	Section at primary nozzle exit
2	Section at mixing stack exit
f	Film or wall cooling
m	Mixed flow or mixing stack
or	Orifice
p	Primary
s	Secondary
t	Tertiary (Cooling)

u	Uptake
w	Mixing stack inside wall

<u>Computer Tabulated Data</u>

DPOR	Pressure differential across the orifice (in. H_2O)
POR	Static pressure at the orifice (in. H_2O)
PSEC	Static pressure at the mixing stack entrance (in. H_2O)
PTER	Static pressure in the tertiary air plenum (in. H_2O)
PUPT	Static pressure in the uptake (in. H_2O)
TAMB	Ambient air temperature (^oF)
TOR	Air temperature at the orifice (^oF)
TUPT	Temperature of air in the uptake (^oF)
UM	Average velocity in the mixing stack (ft/sec)
UP	Primary flow velocity at primary nozzle
UUPT	Primary flow velocity in uptake (ft/sec)
UPT MACH	Uptake Mach number
UE	Average velocity at the mixing stack exit (ft/sec)
WM	Mass flow rate from mixing stack (lbm/sec)
WP	Mass flow from primary nozzles (lbm/sec)
WS	Secondary mass flow rate (lbm/sec)
WT	Tertiary mass flow rate (lbm/sec)

I. INTRODUCTION

The current shipbuilding trend of today's Navy is leading to a large inventory of gas-turbine powered ships. Their lower manning requirements, high horsepower to specific weight, and competitive specific fuel consumption have made the gas-turbine power plant extremely attractive for present and future ship propulsion applications. Gas turbines require large amounts of cooling air in addition to that required for combustion. As a result, air-fuel ratios of four to five times those of conventional power plants are required. Large quantities of hot exhaust gases are therefore generated. The exhaust gas temperatures often run as high as twice those for conventional plants. These exhaust gases contribute to greater thermal and corrosive damages to the mast, superstructure and electronics equipment mounted thereon. Also, the hot plume can cause aircraft control problems for helicopter operations, and generate a high infrared signature from both the gases and the external surfaces of the stack.

The temperature and volume of the exhaust gases is set by the gas turbine operating conditions. Therefore some method must be employed to cool the gases and counter the problems associated with the exhaust. Several methods have been employed to recover waste heat from gas turbines such as the

waste heat boiler and the RACER (Rankine Cycle Energy Recovery) system. A by-product of these systems is a reduction in exhaust gas temperatures.

An extremely simple, effective method of reducing the exhaust gas temperature is to employ the use of a gas eductor. This system can produce the desired effects with no external system connections and has no moving parts. The gas eductor system, properly dimensioned, produces turbulent mixing of the exhaust gases and secondary or ambient air, thereby reducing the overall exit temperature of the exhaust gases. The addition of a shroud on the mixing stack will also provide a film cooled outer stack. Back pressures are minimized when compared to other systems, and the resultant negative pressures along the mixing stack can be utilized to induce a tertiary air flow to provide additional cooling to the shroud through ports in the mixing stack. The gas eductor system is presently in use on several naval vessels. A positive feature of gas eductor systems is that they can be used in conjunction with waste heat recovery systems, such as the RACER system, with minor modifications.

This thesis is a further extension of research conducted by Ellin [Ref. 1], Moss [Ref. 2], Lemke and Staehli [Ref. 3], Shaw [Ref. 4], Ryan [Ref. 5], Davis [Ref. 6], and Drucker [Ref. 7] on the cold flow eductor model testing facility.

The eductor model testing facility constructed by Ellin consists of an uptake, centrifugal compressor, primary flow

nozzles, mixing stack, and a means to control and measure the primary and secondary air flows. Figures 1 and 2 show the general test model layout and terminology used in the model. The primary air flow in the testing facility represents a gas turbine's hot exhaust gas. The secondary air flow is ambient air induced into the mixing stack entrance by the primary air flow utilizing the gas eductor concept. Ellin's research determined that a four primary flow nozzle configuration was preferable to either three or five nozzle systems. Ellin also determined that nozzle length has little, if any, effect on the overall system performance. He verified the independence of the one-dimensional gas eductor modelling correlation parameters used on the flow rate or Mach number. He then showed that the one-dimensional analysis provided good correlation of data for Mach numbers from 50 to 145 percent of the design Mach number of 0.063.

Moss investigated the effects of the stand-off distance (the distance between the exit plane of the primary flow nozzles and the entrance plane of the mixing stack). For non-dimensional analysis, the stand-off distance is divided by the mixing stack diameter to give the S/D ratio. Moss determined that the optimum S/D ratio was 0.5, which maximizes eductor pumping. He also explored the effects of adding a conical transition piece at the mixing stack entrance. His experiments showed that the transition piece produced a slightly degraded system performance.

Lemke and Staehli conducted research utilizing various mixing stack geometric configurations and area ratios of primary nozzles. The area ratio for nozzles is defined as the cross-sectional area of the mixing stack divided by the total cross-sectional area of the primary nozzles. The results of their research showed that decreasing the nozzle area ratio from 3.0 to 2.5 decreased back pressure but also decreased the eductor's pumping coefficient. They investigated the effects of adding a solid diffuser, a two-ring diffuser, and a three-ring diffuser to the exit region of the mixing stack, a ported mixing stack, and a shroud for the mixing stack. They utilized mixing stack length-to-diameter ratios of 2.5 and 3.0. They demonstrated with these various geometries that the pumping coefficient can be improved without an increase in back pressure and that sufficient tertiary air flow can be produced to provide film cooling and additional mixing air.

Davis conducted research to study the effects of tilting and rotating the primary nozzles on the eductor pumping capacity and stack turbulent mixing. He conducted tests on various tilt and rotation combinations with the optimum combination being a 15 degree tilt angle and a 20 degree rotation angle. He maintained the nozzle area ratio at 2.5 and the stand-off ratio (S/D) at 0.5. Davis then tested the effects of shortening the mixing stack length using L/D ratios of 1.75,

1.5, and 1.25 His research indicated that the same overall performance could be realized using a much reduced L/D.

Drucker conducted research investigating the effects on eductor system overall performance of reducing the mixing stack length, slotting the stack, and adding a shroud-diffuser ring arrangement. He demonstrated that tertiary pumping can be increased by increasing the diffuser angle and slotting the stack. His experiments also showed that a shroud-diffuser ring configuration can provide film cooling which in turn provides an effective thermal shield for the mixing stack.

The object of this thesis is to investigate the effects on eductor system performance of using fluted primary flow nozzles. Four nozzle and single nozzle arrangements were tested using different mixing stack lengths that provided L/D ratios of 2.0, 1.75, and 1.5. The stand-off ratio was maintained at 0.5.

II. THEORY AND ANALYSIS

This thesis is a further extension of the work conducted by Ellin, Moss, Lemke and Staehli, Ryan, Davis and Drucker [Refs. 1,2,3,4,5,6, and 7] and uses the same one-dimensional analysis of a simple eductor system. Similarity between the basic geometries tested by previous researchers was maintained to correlate data and preserve the error analysis conducted by Ellin. The dimensionless parameters controlling the flow phenomena used previously were also used in the present research along with the basic means of data analysis and presentation. Dynamic similarity was maintained by using Mach number similarity to establish the gas eductor model's primary flow rate.

Although the analysis presented here is for an eductor model with only primary and secondary air flows, the basic discussion applies as well to systems with primary, secondary, and tertiary flows. Systems with tertiary and film or wall cooling air flows have been non-dimensionalized with the same base parameters as the secondary air flow and have been calculated using the same one-dimensional analysis. This allows easier comparison of tabulated and graphic results. Parameters pertaining to the secondary systems are subscripted with an "s" and those relating to the tertiary box are subscripted with a "t".

A. MODELING TECHNIQUE

Dynamic similarity between the models tested and an actual prototype was maintained by using the same primary air flow Mach number. For the primary air flow Mach number used (0.062), and based on the average flow properties within the uptake and the hydraulic diameter of the uptake, the air flow through the eductor system is turbulent ($Re>10^5$). As a consequence of this, momentum exchange is predominant over shear interaction, and the kinetic and internal energy terms are more influential on the flow than are viscous forces. It can also be shown that the Mach number represents the ratio of kinetic energy of a flow to its internal energy and is, therefore, a more significant parameter than the Reynolds number in describing the primary flow through the uptakes.

B. ONE-DIMENSIONAL ANALYSIS OF A SIMPLE EDUCTOR

The theoretical analysis of an eductor may be approached in two ways. One method attempts to analyze the details of the mixing process of the primary and secondary air streams as it takes place inside the mixing stack. This requires an interpretation of the mixing phenomenon which, when applied to a multiple nozzle system, becomes extremely complex. The other method, which was chosen here, analyzes the overall performance of the eductor system and is not concerned with the actual mixing process. To avoid repetition with previous reports, only the main parameters and assumptions will be

represented here. A complete derivation of the analysis used can be found in References [1] and [8]. The one-dimensional flow analysis of the simple eductor system described depends on the simultaneous solution of the continuity, momentum and energy equations coupled with the equation of state, all compatible with specific boundary conditions.

The idealizations made for simplifying the analysis are as follows:

1. The flow is steady state and incompressible.

2. Adiabatic flow exists throughout the eductor with isentropic flow of the secondary stream from the plenum to the throat or entrance of the mixing stack and irreversible adiabatic mixing of the primary and secondary streams occurs in the mixing stack.

3. The static pressure across the flow at the entrance and exit planes of the mixing-stack is uniform.

4. At the mixing-stack entrance the primary flow velocity U_p and temperature T_p are uniform across the primary stream, and the secondary flow velocity U_s and temperature T_s are uniform across the secondary stream, but U_p does not equal U_s, and T_p does not equal T_s.

5. Incomplete mixing of the primary and secondary streams in the mixing stack is accounted for by the use of a non-dimensional momentum correction factor K_m which relates the actual momentum rate to the pseudo-rate based on the bulk-average velocity and density and by the use of a non-dimensional

kinetic energy correction factor K_e which relates the actual kinetic energy rate to the pseudo-rate based on the bulk-average velocity and density.

6. Both gas flows behave as perfect gases.

7. Changes in gravitational potential energy are negligible.

8. Pressure changes P_{s0} to P_{s1} and P_1 to P_a are small relative to the static pressure so that the gas density is essentially dependent upon temperature and atmospheric pressure.

9. Wall friction in the mixing stack is accounted for with the conventional pipe friction factor term based on the bulk-average flow velocity U_m and the mixing stack wall area A_w.

The following parameters, defined here for clarity, will be used in the following development.

$\frac{A_p}{A_m}$	area ratio of primary flow area to mixing stack cross sectional area
$\frac{A_w}{A_m}$	area ratio of wall friction area to mixing stack cross sectional area
K_p	momentum correction factor for primary flow
K_m	momentum correction factor for mixed flow
f	wall friction factor

Based on the continuity equation, the conservation of mass principle for steady flow yields

$$W_m = W_p + W_s + W_t \tag{1}$$

where

$$W_p = \rho_p U_p A_p$$
$$W_s = \rho_s U_s A_s$$
$$W_t = \rho_t U_t A_t \qquad (1a)$$
$$W_m = \rho_m U_m A_m$$

All of the above velocity and density terms, with the exception of ρ_m and U_m, are defined without ambiguity by the virtue of idealizations (3) and (4) above. Combining equations (1) and (1a) above, the bulk average velocity at the exit plane of the mixing stack becomes

$$U_m = \frac{W_s + W_t + W_p}{\rho_m A_m} \qquad (1b)$$

where A_m is fixed by the geometric configuration and

$$\rho_m = \frac{p_a}{RT_m}$$

where T_m is calculated as the bulk average temperature from the energy equation (9) below. The momentum equation stems from Newton's second and third laws of motion and is the conventional force and momentum-rate balance in fluid mechanics.

$$K_p\left(\frac{W_p U_p}{g_c}\right) + \left(\frac{W_s U_s}{g_c}\right) + \left(\frac{W_t U_t}{g_c}\right) + P_1 A_1 = K_m\left(\frac{W_m U_m}{g_c}\right) + P_2 A_2$$
$$+ F_{fr} \qquad (3)$$

Note the introduction of idealizations (3) and (5). To account for possible non-uniform velocity profiles across the primary nozzle exit, the momentum correction factor K_p is introduced here. It is defined in a manner similar to that of K_m and by idealization (4), and supported by work conducted by Moss, it is set equal to unity. K_p is carried through this analysis only to illustrate its effect on the final result. The momentum correction factor for the mixing stack exit is defined by the relation

$$K_m = \frac{1}{W_m U_m} \int_0^{A_m} U_m^2 \rho_2 dA \tag{4}$$

where U_m is evaluated as the bulk-average velocity from equation (1b). The wall skin friction factor F_{fr} can be related to the flow stream velocity by

$$F_{fr} = f A_w \left(\frac{U_m^2 \rho_m}{2 g_c}\right) \tag{5}$$

using idealization (9). As a reasonably good approximation for turbulent flow, the friction factor may be calculated from the Reynolds number

$$f = 0.046 \, (Re_m)^{-0.2}. \tag{6}$$

Applying the conservation of energy principle to the steady flow system in the mixing stack between the entrance and exit planes,

$$W_p\left(h_p + \frac{U_p^2}{2g_c}\right) + W_s\left(h_s + \frac{U_s^2}{2g_c}\right) + W_t\left(h_t + \frac{U_t^2}{2g_c}\right)$$

$$= W_m\left(h_m + K_e\frac{U_m^2}{2g_c}\right) \tag{7}$$

neglecting potential energy of position changes (idealization 7). Note the introduction of the kinetic energy correction factor K_e, which is defined by the relation

$$K_e = \frac{1}{W_m U_m^2} \int_0^{A_m} U_2{}^3 \rho_2 \, dA \tag{8}$$

It may be demonstrated that for the purpose of evaluating the mixed mean flow temperature T_m, the kinetic energy terms may be neglected to yield

$$h_m = \frac{W_p}{W_m} h_p + \frac{W_s}{W_m} h_s + \frac{W_t}{W_m} h_t \tag{9}$$

where $T = \emptyset(h_m)$ only, with the idealization (6).

The energy equation for the isentropic flow of the secondary air from the plenum to the entrance of the mixing stack may be shown to reduce to

$$\frac{P_o - P_s}{\rho_s} = \frac{U_s^2}{2g_c} \tag{10}$$

similarly, the energy equation for the tertiary flow reduces to

$$\frac{P_o - P_t}{\rho_t} = \frac{U_t^{\,2}}{2g_c}$$

The previous equations may be combined to yield the vacuum produced by the eductor action in either the secondary or tertiary air plenums. For the secondary air plenum, the vacuum produced is

$$P_a - P_{os} = \frac{1}{g_c A_m}\left(K_p \frac{W_p^{\,2}}{A_p \rho_p} + \frac{W_s^{\,2}}{A_s \rho_s}\left(1 - \frac{1}{2}\frac{A_m}{A_s}\right) - \frac{W_m^{\,2}}{A_m \rho_m}\left(K_m + \frac{f}{2}\frac{A_w}{A_m}\right)\right) \tag{11}$$

where it is understood that A_p and ρ_p apply to the primary flow at the entrance to the mixing stack, A_s and ρ_s apply to the secondary flow at this same section, and A_m and ρ_m apply to the mixed flow at the exit of the mixing stack system. P_a is atmospheric pressure, and is equal to the pressure at the exit of the mixing stack. A_w is the area of the inside wall of the mixing stack.

For the tertiary air plenum, the vacuum produced is

$$P_a - P_{ot} = \frac{1}{g_c A_m}\left(K_p \frac{(W_p + W_s)^2}{(A_p \rho_p + A_s \rho_s)} + \frac{W_t^{\,2}}{A_t \rho_t}\left(1 - \frac{1}{2}\frac{A_m}{A_t}\right)\right.$$
$$\left. = \frac{W_m^{\,2}}{A_m \rho_m}\left(K_m + \frac{f}{2}\frac{A_w}{A_m}\right)\right) \tag{11a}$$

where the primary flow now consists of both the primary and secondary flows.

C. NON-DIMENSIONAL FORM OF THE SIMPLE EDUCTOR EQUATION

In order to provide the criteria of similarity of flows with geometric similarity, the non-dimensional parameters which govern the flow must be determined. The means chosen for determining these parameters was to normalize equations (11) and (11a) with the following dimensionless groupings.

$$P^* = \frac{\frac{P_a - P_{os}}{\rho_s}}{\frac{U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumped head $P_a - P_{os}$ for the secondary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow

$$PT^* = \frac{\frac{P_a - P_{ot}}{\rho_t}}{\frac{U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumped head $P_a - P_{os}$ for the tertiary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow

$$W^* = \frac{W_s}{W_p}$$

a flow rate ratio, secondary to primary mass flow rate

$$WT^* = \frac{W_t}{W_p}$$

a flow rate ratio, tertiary to primary mass flow rate

$$T^* = \frac{T_s}{T_p}$$

an absolute temperature ratio, secondary to primary

$$TT^* = \frac{T_t}{T_p}$$

an absolute temperature ratio, tertiary to primary

$\rho_s^* = \dfrac{\rho_s}{\rho_p}$ a flow density ratio of the secondary to primary flows. (Note that since the fluids are considered perfect gases,

$$\rho_s^* = \frac{T_p}{T_s} = \frac{1}{T_s^*})$$

$\rho_t^* = \dfrac{\rho_t}{\rho_p}$ a flow density ratio of the tertiary or film cooling flow to primary flows. (Note that since the fluids are considered perfect gases,

$$\rho_t^* = \frac{T_p}{T_t} = \frac{1}{T_t^*})$$

$A_s^* = \dfrac{A_s}{A_p}$ an area ratio of secondary flow area to primary flow area

$A_t^* = \dfrac{A_t}{A_p}$ an area ratio of tertiary flow area to primary flow area

With these non-dimensional groupings, equations (11) and (11a) can be rewritten in dimensionless form. Since both equations follow the same format, only the results for the secondary air plenum will be presented here.

$$\frac{P^*}{T^*} = 2\,\frac{A_p}{A_m}((K_p - \frac{A_p}{A_m}\beta) - W^*(K_p + T^*)\,\frac{A_p}{A_m}\,\beta$$

$$+ W^{*2}T^*(\frac{1}{A^*}(K_p - \frac{A_m}{2A^*A_p}) - \frac{A_p}{A_m}\,\beta)) \qquad (12)$$

where

$$\beta = K_m + \frac{f}{2}\,\frac{A_w}{A_m}\;.$$

This may be rewritten as

$$\frac{P^*}{T^*} = C_1 + C_2 W^*(T + 1) - C_3 W^{*2} T^* \tag{13}$$

where

$$C_1 = 2\frac{A_p}{A_m}(K_p - \frac{A_p}{A_m}\beta),$$

$$C_2 = -\left(\frac{A_p}{A_m}\right)^2 \beta, \text{ and}$$

$$C_3 = 2\frac{A_p}{A_m}\left(\frac{1}{A^*} - \frac{A_m}{2A^*A_p}\beta - \frac{A_p}{A_m}\beta\right).$$

As can be seen from equation (13),

$$P^* = F(W^*, T^*).$$

The additional dimensionless quantities listed below were used to correlate the static pressure distribution down the length of the mixing stack.

$PMS^* = \dfrac{\frac{PMS}{\rho_s}}{\frac{U_p^2}{2g_c}}$ — a pressure coefficient which compares the pumping head $\frac{PMS}{\rho_s}$ for the secondary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow, where PMS = static pressure along the mixing stack length

$\frac{X}{D}$ — ratio of the axial distance from the mixing stack entrance to the diameter of the mixing stack.

D. EXPERIMENTAL CORRELATION

For the geometries and flow rates investigated, it was confirmed by Ellin and Moss [Ref. 1,2] that a satisfactory correlation of the variables P*, T*, and W* takes the form

$$\frac{P^*}{T^*} = f(W^*T^{*n}) \tag{1}$$

where the exponent 'n' was determined to be equal to 0.44. The details of the determination of n=0.44 as the correlating exponent for the geometric parameters of the gas eductor model being tested is given in Reference [1]. To obtain a gas eductor model's pumping characteristic curve, the experimental data is correlated and analyzed by using equation (1), that is, P*/T* is plotted as a function of $W^*T^{*0.44}$. This correlation is used to predict the open-to-the-environment operating point for the gas eductor model. Variations in the model's geometry will change the pumping ability, which can be evaluated by the plot of equation (1). For ease of discussion, $W^*T^{*0.44}$ will be referred to as the pumping coefficient in this report.

III. MODEL GEOMETRIES

The gas eductor system in this report made use of a single primary flow uptake, fluted primary nozzles and a straight unshrouded stack.

A. PRIMARY NOZZLE AND BASE PLATE CONFIGURATIONS AND GEOMETRIES

The main body of this research was to study the effects of fluted primary nozzles on the gas eductor system performance. The nozzles were constructed from an aluminum-filled epoxy compound using a multi-step process. The cross sectional area was maintained at 10.752 square inches from circular inlet to fluted outlet. Initially, a wax model was constructed that was a true representation of the desired inside shape of the nozzle. This wax model was used as a lost wax pattern and a female silicone rubber mold was made. From this a male silicone rubber mold and a male plaster mold was formed. The plaster mold was built up 1/8 inch using wax and placed in the center of a six inch metal sleeve. Silicone rubber was poured into the sleeve to form a female mold. The two silicone rubber molds (male and female) were placed in the six inch metal sleeve and aluminum-filled epoxy compound poured between them. The entire mold was then placed in an evacuated chamber to remove any air bubbles. The different parts of the molding

process are pictured in Figures 5 through 10 and dimensions of the primary nozzles are shown in Figures 11 and 12.

The four nozzle base plate was constructed from acrylic plexiglass flat stock. Four recess holes were machined to accept the nozzles, and they were in turn machined to a 0.5 inch radius on the underside to present a smooth flow entrance region for the nozzles. The outer edge of the base plate was machined so that the whole base plate fit inside a matching aluminum ring. The construction was such that the base plate could be rotated within the ring, primary flow pressure kept the two concentric surfaces mated which eliminated seals, and the base plate could not be ejected from the uptake by the considerable dynamic pressures associated with the high velocity primary air flow. Four symmetrically located locking cams allowed the base plate and installed nozzles to be locked in place. The base plate with nozzles installed is shown in Figure 13.

The single nozzle base plate was also constructed from acrylic plexiglass, machined to accept the nozzle, and machined to a 0.5 inch radius on the underside. Rotatability of the nozzle was not provided for, however, the nozzle and base plate could be rotated as a unit in the uptake duct when required. The single nozzle with baseplate is depicted in Figure 14.

B. MIXING STACK CONFIGURATIONS

The mixing stack used in the four nozzle testing was manufactured from nominally 12 inch O.D. and 11.7 inch I.D. PVC agricultural water irrigation pipe. The L/D for this stack was 1.5.

The mixing stacks used in the single nozzle testing were manufactured from nominally 6 inch O.D. and 5.75 inch I.D. rolled steel pipe. The L/D ratios used were 2.0, 1.75 and 1.5.

Pressure taps, 45^{o} apart circumferentially, were installed at 0.25 X/D increments longitudinally along the stack wall to obtain the mixing stack pressure distribution. The 12 inch and 6 inch mixing stacks are pictured in Figure 15.

C. UPTAKE GEOMETRY

The uptake system was modified for the single nozzle testing. In order to maintain the primary nozzle area ratio as close as possible to 2.5, an additional 5 foot long transition piece was added to reduce the uptake diameter from 12 inches to 6 inches. The straight section of the uptakes was manufactured from the same 6 inch O.D. rolled steel pipe used for the mixing stacks. The primary nozzle area ratio obtained for this system was 2.42.

IV. EXPERIMENTAL APPARATUS

Air is supplied to the primary nozzles by means of a centrifugal compressor and associated ducting schematically illustrated in Figure 1. The mixing stack configuration being tested is placed inside an air plenum containing an airtight partition so that two separate air flows, secondary and tertiary, may be measured. The air plenum facilitates the accurate measurement of secondary and tertiary air flows by using ASME long radius flow nozzles.

A. PRIMARY AIR SYSTEM

The circled numbers found in this section refer to circled locations on Figure 1. The primary air ducting is constructed of 16-gauge steel with 0.635 cm (0.25 in) thick steel flanges. The ducting sections were assembled using 0.635 cm (0.25 in) bolts with air drying silicone rubber seals between the flanges of adjacent sections. Entrance to the inlet ducting 1 is from the exterior of the building through a 91.44 cm (3.0 ft) square to a 30.48 cm (1.0 ft) square reducer, each side of which has the curvature of a quarter ellipse. A transition section 2 then changes the 30.48 cm (1.0 ft) square section to a 35.31 cm (13.90 in) diameter circular section 3 . This circular section runs approximately 9.14 m (30 ft) to the centrifugal compressor inlet.

A standard ASME square edged orifice 4 is located 15 diameters downstream of the entrance reducer and 11 diameters upstream of the centrifugal compressor inlet, thus insuring stability of flow at both the orifice and compressor inlet. Piezometer rings 5 are located one diameter upstream and one-half diameter downstream of the orifice. The duct section also contains a thermocouple just downstream of the orifice. Primary flow is measured by means of the standard ASME square edged orifice designed to the specifications given in the ASME power test code [Ref. 9]. The 17.55 cm (6.902 in) diameter orifice used was constructed out of 304 stainless steel 0.635 cm (0.25 in) thick. The inside diameter of the duct at the orifice is 35.31 cm (13.90 in) which yields a beta ($\beta = d/D$) of 0.497. The orifice diameter was chosen to give the best performance in regard to pressure drop and pressure loss across the orifice for the primary air flow rate used (1.71 kg/sec (3.77 lbm/sec)).

The centrifugal compressor 7 used to provide primary air to the system is a Spencer Turbo Compressor, catalogue number 25100-H, rated at 6000 cfm at 2.5 psi back pressure. The compressor is driven by a three phase, 440 volt, 100 horsepower motor.

A manually operated sliding plate variable orifice 6 was designed to constrict the flow symmetrically and facilitate fine control of the primary air flow. During operation, the

butterfly valve 8 , located at the compressor's discharge, provided adequate regulation of primary air flow, eliminating the necessity of using the sliding plate valve. The sliding plate valve was positioned in the wide-open position for all data runs.

On the compressor discharge side, immediately downstream of the butterfly valve, is a round to square transition 9 followed by a 90 degree elbow 10 and a straight section duct 11 . All ducting to this point is considered part of the fixed primary air supply system. A transition section 12 is fitted to this last square section which reduces the duct cross section to a circular section 29.72 cm (11.17 in) in diameter. This circular ducting tapers down to a diameter of 26.30 cm (11.5 in) to provide the primary air inlet to the eductor system being tested. For the single nozzle testing an additional transition piece was inserted, further reducing the diameter of the duct to 14.60 cm (5.75 in). The transition is located far enough upstream of the model to insure that the flow reaching the model is fully developed.

B. SECONDARY AIR PLENUM

The secondary air plenum, shown in Figures 1, 2, and 3, is constructed of 1.905 cm (0.75 in) plywood and measures 1.22 m by 1.22 m by 1.88 m (4.6 ft by 4.0 ft by 6.17 ft). It serves as an enclosure that can contain all or only part of the eductor model and still allow the exit plane of the

mixing stack to protrude. The purpose of the secondary air plenum is to serve as a boundary through which secondary air for the eductor system must flow. Long radius ASME nozzles, designed in accordance with ASME power test codes [Ref. 9] and constructed of fiberglass, penetrate the secondary air plenum, thereby providing the sole means for metering the secondary air reaching the eductor as shown in Figures 1 through 4. Appendix D of Reference [1] outlines the design and construction of the secondary air flow nozzles. By measuring the temperature of the air entering and the pressure differential across the ASME flow nozzles, the mass flow rate of secondary air can be determined. Flexibility is provided in measurement for the mass flow rate of secondary air by employing flow nozzles with three different throat diameters: 20.32 cm (8 in), 19.16 cm (4 in), and 5.08 cm (2 in). By using a combination of flow nozzles, a wide variety of secondary cross sectional areas can be obtained.

A secondary air flow straightener, shown in Figures 1 and 2, consisting of a double screen is installed 1.22 m (4 ft) from the open end of the secondary air plenum, between the ASME long radius nozzles and the primary air flow nozzles. The purpose of the straightener is to reduce any swirl effect that could result when only a small secondary air flow area exists.

C. TERTIARY AIR PLENUM

The tertiary air plenum, shown in Figures 1, 2, 18 and 19, is constructed of 1.90 cm (0.75 in) plywood and measures 1.22 m by 1.22 m by 1.22 m (4.0 ft by 4.0 ft by 4.0 ft). It serves as an enclosure that completely surrounds the mixing stack and allows the exit and entrance regions to protrude. An airtight rubber diaphragm type seal, schematically illustrated in Figure 2, is located at the entrance to the tertiary plenum (seal between secondary and tertiary plenums). The seal slides over the mixing stack with a nominal 1/8 inch clearance and a bead of silicone rubber is used to make the final seal. The interior of the tertiary air plenum is pictured in Figures 18 and 19. The stand which holds the mixing stack can be seen mounted inside the plenum.

D. INSTRUMENTATION

Pressure taps for measuring static pressures are located inside the primary air uptakes just prior to the primary nozzles, inside the secondary air plenum, inside the tertiary air plenum, and at various points on the model. A variety of manometers, pictured in Figure 22, were used to indicate the pressure differentials. A schematic representation of the pressure measuring instrumentation is illustrated in Figures 21 and 23. Monitoring of each of the various pressures was facilitated by the use of a scanivalve and a multiple valve manifold. The scanivalve was used to select the

pressure tap to be read, while the multiple valve manifold allowed selection of the optimum manometer for the pressure being recorded. A vent was included in the multiple valve manifold which provided a means of venting the manometers between pressure readings. The valve manifold provided a selection of a 15.24 cm (6.0 in) inclined water manometer, and a 5.08 cm (2.0 in) inclined water manometer. In addition, the following dedicated manometers were used in the system: a 50.80 cm (20.0 in) single column water manometer connected to the primary air flow just prior to the primary nozzles, a 1.27 m (50.0 in) U-tube water manometer with each leg connected to the piezometric ring on either side of the orifice plate in the air inlet duct, and a 2.55 cm (1.0 in) inclined water manometer connected to the upstream piezometric ring. For the single nozzle testing the U-tube manometer was replaced by a 15.24 cm (6.0 in) inclined differential water manometer.

Primary air temperatures, measured at the orifice outlet and just prior to the primary nozzles, are measured with copper-constantan thermocouples. The thermocouples are in assemblies manufactured by Honeywell under the trade name Megapak. Polyvinyl covered 20 gauge copper-constantan extension wire is used to connect the thermocouples to an Omega Digital Thermometer, Model Number 2176A, which provided temperatures in degrees Fahrenheit or Celsius. A copper-constantan thermocouple was used to measure secondary/ tertiary ambient air temperature.

Velocity profiles at the mixing stack exit plane are obtained by using a pitot tube mounted on a slide bar which is scribed in one-tenth inch intervals for accuracy and ease of measurement. The slide bar could be mounted to read along the horizontal or diagonal. The pitot tube is fastened to the slide bar with two clamp blocks and can be adjusted to bring the pitot opening flush with the end of the stack. In conjunction with the pitot tube, a 50.8 cm (20.0 in) single column water manometer or a 15.24 cm (6.0 in) inclined water manometer were used to measure the exit pressures. Threaded studs were used to aid in positioning the traverse (slide) bar in the desired position. The traverse bar and pitot tube assembly was secured to a wood stand with the use of four nuts. The test stand clamps tightly to the exit end of the tertiary plenum. This assembly can be seen in Figure 18.

E. ALIGNMENT

The alignment of the mixing stack with the primary flow nozzles is accomplished by using two round alignment plugs, a nozzle alignment plate and a 0.75 inch O.D. steel alignment bar. The two circular alignment plugs are inserted into opposite ends of the mixing stack, and the nozzle alignment plate is then carefully inserted over the straight nozzles. The steel alignment bar is then inserted through the center-line holes in the alignment plugs and brought up to the centerline hole in the nozzle alignment plate. The three

axis mounting stand, pictured in Figure 18, is adjusted until the alignment bar can be fully inserted into the nozzle alignment plate and recess in the nozzle base plate without difficulty.

For the single nozzle configuration the nozzle is removed and a third circular alignment plug is inserted in the uptake exit. The steel alignment bar is then inserted in the mixing stack as before and the mounting stand adjusted until the alignment bar can be fully inserted into the uptake plug.

V. EXPERIMENTAL METHOD

Evaluation of the eductor model requires the experimental determination of pressure differentials across the ASME long radius flow nozzles, temperatures of primary and induced air flows, internal mixing stack pressure distributions, and mixing stack exit velocity profiles from pitot tube pressure readings. In addition, base plate rotations angles are used to get a general understanding of the flow patterns within the mixing stack. These experimentally determined quantities are then reduced with the aid of a computer to obtain pumping coefficients, induced air flow rates, pressure distributions and flow distributions in the mixing stack, and mixing stack velocity profiles at the exit plane of the mixing stack.

The following sections address the individual performance criteria used to evaluate the eductor. Circled numbers refer to regions located on the representative plots used in the evaluation process.

A. PUMPING COEFFICIENT

The secondary pumping coefficient and the tertiary pumping coefficient provide a basis for analyzing the eductor's pumping capability. Changes in stack geometries such as L/D ratio's, slotting, shrouding, diffuser rings, and spacing between stack and shroud and between shroud and diffuser

rings will alter the eductor's pumping performance and the pumping coefficient. The pumping coefficients for the model should correspond to the coefficients for the shipboard eductor system. At the shipboard operating point, the eductor is exposed to no restrictions in the secondary or tertiary air flows. In the model, this is simulated by completely opening the air plenums to the environment. Unfortunately, at this condition, the secondary and/or tertiary air flow rates can not be measured. The eductor model's characteristics are first established over the measurable flow range and then extrapolated to the desired operating point.

The data for this extrapolation is established by varying the associated induced air flow rate, either secondary or tertiary, from zero to its maximum measurable rate. These rates are determined by sequentially opening the ASME flow nozzles mounted in the appropriate plenum and recording the pressure drop across the nozzles. Values for nozzle cross sectional areas, pressure drops, induced flow air temperatures, and barometric pressures are then used to calculate the dimensionless parameters P^*/T^*, $W^*T^{*0.44}$, PT^*/TT^*, and $WT^*TT^{*0.44}$. The dimensionless parameters are then plotted as illustrated in Figure 24. The data point 1 corresponds to closing all ASME flow nozzles. Data points in region 2 correspond to opening most of the ASME flow nozzles and the final point corresponds to opening all flow nozzles. Although the data points in region 2 appear to be zero or nearly so,

they do have a small finite value. The uncertainty associated with these points is relatively high. The data points in region 3 provide the most consistent and accurate data. Extrapolation of the pumping characteristic curve to intersect the zero P*/T* or PT*/TT* abscissa locates the appropriate operating point for the eductor model configuration.

B. INDUCED AIR FLOWS

Secondary and tertiary air flows are induced flows. The secondary air flow is the amount of air induced by the primary nozzles which is mixed within the mixing stack with primary air to reduce the exhaust gas temperature. Tertiary or film cooling air flow is the amount of air induced by the low pressure areas along the mixing stack.

C. PRESSURE DISTRIBUTION IN THE MIXING STACK

The axial pressure distribution in the mixing stack is obtained by taking static pressure readings from pressure taps attached to the stack in two rows. In the cold flow test facility, the mixing stack is located horizontally in the tertiary plenum. The first row is located on the top of the mixing stack, and the second row is offset 45 degrees from the first row as shown in Figures 16 and 17. The pressure taps were located 0.25 mixing stack diameters apart. The dimensionless mixing stack pressure term, PMS*, as derived in Section II is calculated from static pressure data. PMS* is plotted versus X/D pressure tap locations

to obtain the mixing stack pressure distribution. A sample distribution is shown in Figure 25. Region 1 is located at the entrance of the mixing stack, and it has the greatest negative pressure readings. Pressures near region 2, located toward the end of the mixing stack, are significantly less negative than those in region 1.

D. MIXING STACK ROTATION ANGLE

The nozzles produce a symmetric flow consisting of high and low pressure areas along the axis of the mixing stack. Pressure taps at position 'A' were used to record the peaks while the position 'B' taps were used to record the lower pressure regions. A rotatable base plate was used to scan the entire circumference of the mixing stack at each L/D position and thereby obtain a record of the varying axial pressure distribution. This allowed the peaks and troughs to be rotated to the stationary pressure taps for data acquisition. The base plate rotation angle, ψ, is recorded for each pressure tap position, and when plotted, provides a rough indication of the flow pattern variations.

Tests were conducted early in Davis' research to determine the sensitivity of the rotation angles. Results showed that changes as small as one degree of rotation could cause large pressure changes while at other times the base plate could be rotated 30 degrees without any pressure changes.

E. VELOCITY TRAVERSES

The velocity traverses are generated by traversing the pitot tube in measured increments across the horizontal and diagonal lines as indicated in Figures 16 and 17. Stagnation pressure readings are read from the 20 inch vertical manometer or the 6 inch inclined manometer and combined with atmospheric pressure and ambient temperature to calculate mixing stack exit velocities in units of feet per second. Computer generated two-dimensional plots of the velocity traverses can then be used to get indications of mixing, wall effects, and primary flow core information.

The sample horizontal velocity profile shown in Figure 26 shows two, essentially primary flow peaks at regions 2 and 4. Regions 1 and 5 are essentially secondary induced flows and show some wall effects. Region 3 should be symmetrically located at the center of the stack, however misalignment of the base plate, non-symmetric nozzle placement, non-circular mixing stack, and unequal pumping by the primary nozzles are a few of the things that could cause the center trough to appear slightly displaced. Data points between regions 2 and 4 should overlap those on the diagonal velocity plot.

The sample diagonal velocity profile shown in Figure 27 shows peaks and troughs at slightly different locations on the stack. This is primarily due to the geometry of the

fluted nozzles. Regions 2 and 4 are primary flow peaks and correspond to those in the horizontal profile. Regions 1 and 5 exhibit wall effects to a lesser degree.

The dashed line in both sample profiles are rough indications of what a fully mixed flow profile should look like. The goal is to have generally flat overall profiles as an indication of enhanced mixing. Sharp peaks and troughs should therefore be minimized. The comparison plots of the two profiles serve to determine data accuracy, the interaction of the flows, and base plate misalignment which can seriously skew the profiles.

VI. DISCUSSION OF EXPERIMENTAL RESULTS

The discussion of this investigation will be confined mainly to the amount of induced secondary air flow and its mixing with the primary air flow within the mixing stack, mixing of primary and secondary air. Back pressure on the turbine exhaust caused by the eductor system is primarily fixed by the Mach number in the uptake and the area ratio of the nozzles to the uptake flow area which was tested and confirmed by Davis [Ref. 6] and Lemke and Staehli [Ref. 3]. In the case of the four nozzle testing, the nozzle area ratio was maintained at 2.5 and the back pressure remained relaively constant at 6.1 inches of water. The nozzle area ratio was reduced to 2.42 in the single nozzle testing and slightly lower back pressures (5.3 - 5.7 inches of water) were realized.

The tabulated data is presented in the same format as that of Davis and Drucker. During the discussion of this data the following abbreviations will be used; PCD for pumping coefficient, MSD for mixing stack pressure distribution, and VTD for velocity traverse distribution.

The base line data utilized in this research was that taken by Davis using a straight mixing stack, L/D = 1.5 and four round, straight nozzles. This data is presented in Figure 28. Comparisons between this data and that obtained in the fluted nozzle testing will be made to demonstrate the performance of the fluted nozzle concept.

A. FOUR FLUTED NOZZLE CHARACTERISTICS

Data in the four nozzle testing was gathered utilizing a straight mixing stack, L/D = 1.5. The initial data on the fluted nozzles is presented in Figure 29 and Table I. The fluted nozzles produced a PCD of 0.48 versus 0.52 for Davis' straight nozzles. Mixing stack axial pressure distribution was degraded from the straight nozzle configuration. Peak velocities for the fluted nozzles were essentially the same as those obtained by Davis using straight nozzles with the same L/D ratio.

The geometry of the four fluted nozzle configuration and the initial velocity profiles obtained dictated a verification that symmetry of flow existed. This was done by checking velocity traverses with the base plate at 0° rotation and at 45° rotation. This data is presented in Figure 30 and Table II. By comparing the velocity traverse profiles it can be clearly seen that the flow is indeed symmetric.

Moss [Ref. 2] determined that the optimum S/D ratio was 0.5. The possibility existed with the fluted nozzles that the primary flow was being spread out so that a portion of the flow would not enter the mixing stack and thereby decrease the pumping efficiency of the system. A series of PCD checks was conducted at S/D's of 0.5, 0.45, 0.40, 0.35, 0.30, 0.25, and 0.125. This data is presented in Figures 31 through 37 and Tables III through IX. The PCD remained relatively

constant at 0.48 indicating that the pumping efficiency of this system is independent of the S/D ratio (over the range tested) and that the full primary flow from the nozzles was entering the mixing stack.

A comparison of PCD, MSD, and VTD for the straight nozzles and four fluted nozzles is presented in Figure 54. Pumping efficiency for the fluted nozzles was slightly lower than for the straight nozzles. The mixing stack data at position A was significantly more negative at the entrance to the mixing stack in the case of the fluted nozzles while the position B data was slightly less negative at the same point. The velocity profiles for the fluted nozzles were essentially the same as those for the straight nozzles.

B. REDUCED FLUTED LENGTH SECTION CHARACTERISTICS

The four fluted nozzle configuration exhibited a restriction of flow in the region near the center of the nozzle cluster due to the close clearances involved. This is evidenced by the lower peak velocities near the center of the velocity profiles and the fact that the trough at the center of the profiles is not as pronounced as that for the straight nozzles. This resulted in flatter velocity profiles when compared to the straight nozzles. However, the pumping efficiency is decreased and the mixing stack axial pressure distribution is degraded. In order to further test the performance of the fluted nozzles as compared to the straight, it was decided to

incrementally reduce the length of the fluted portion while maintaining the overall nozzle length constant. By reducing the length of the fluted portion, the clearances between the four nozzles at the center of the nozzle cluster became greater and the nozzle configuration approached that of the straight nozzles. Data for 3/4 length fluted nozzles is presented in Figures 38 and 39 and Tables X and XI. The pumping coefficient increased to 0.50 with little change in the mixing stack data. The VTD compares very closely with that of the straight nozzles with the peak velocities being very nearly the same.

Data for 1/2 length fluted nozzles is presented in Figure 40 and Table XII. The nozzle area ratio was increased to 2.64 as a result of a slight reduction in area of the primary nozzles to 10.162 square inches. A further increase in PCD to 0.52 (matching that of Davis' straight nozzles was realized. This increase in PCD is attributed partly to the increased area ratio. No significant improvement in MSD was noted. The VTD compares favorably with that of the straight nozzles. A comparison of the PCD data for full, 3/4 and 1/2 length fluted nozzles is shown in Figure 41. As can be seen, the pumping efficiency increased as the length of the fluted portion of the nozzles was reduced.

C. SINGLE FLUTED NOZZLE CHARACTERISTICS

The single fluted nozzle configuration was tested using mixing stack lengths of 2.0, 1.75, and 1.5. Ellin's [Ref. 1] testing of a four nozzle configuration of his eductor proposals A and B indicated that the uptake Mach number has no effect on pumping coefficient. He also showed an improvement in mixing corresponding to increases in uptake Mach number. For the single fluted nozzle system uptake Mach numbers were varied from 55 percent to 125 percent of the design Mach number. Three values of Mach number were chosen to be evaluated on the straight mixing stack (L/D = 2.0), single fluted nozzle eductor configuration. Each of the three Mach numbers were evaluated with data runs of PCD and MSD data. The processed data can be seen in Tables XIII through XV and Figures 42 through 44. Comparisons of pumping coefficients for 55, 100, and 125 percent of design Mach number show that the pumping coefficient is again independent of Mach number for this eductor configuration. Mixing stack data at all three Mach numbers was essentially the same. The data shows a marked decrease in stack wall negative pressures, MSD, at the greater X/D positions when compared to the data obtained by Davis using his straight nozzles.

A set of velocity profiles was taken at the nozzle exit. These profiles can be seen in Figures 46 and 47. Figure 46 is a velocity profile taken across the wide portion of the

nozzle ("ear to ear") and Figure 47 is the profile taken across the narrow portion ("throat to throat"). These profiles show a uniform primary flow at the exit of the fluted nozzle.

Data for the L/D = 2.0 mixing stack is presented in Figure 48 and Table XVI. The pumping coefficient obtained from this configuration was 0.50 as compared to 0.52 obtained by Davis in his straight nozzle testing. The mixing stack data showed nearly identical negative pressures at small X/D positions but significantly lesser negative pressures at X/D positions from 0.5 to the end of the stack.

Data for the L/D = 1.75 mixing stack is presented in Figure 49 and Table XVII. The PCD obtained was again 0.50 showing no change from the L/D = 2.0 stack. The MSD was also essentially the same as were the velocity profiles.

Data for the L/D = 1.50 mixing stack is shown in Figure 50 and Table XVIII. The PCD obtained was again 0.50. The MSD and VTD were also again the same as the two longer mixing stacks.

A comparison plot of pumping coefficient data is shown in Figure 52. Close examination of the data shows that there is a slight increase in pumping efficiency as the L/D is increased. Figure 53 is a comparison of the axial pressure distribution for the three L/D's. As can be seen the distribution is essentially the same for all three.

Given the velocity profiles at the exit of the primary nozzle shown in Figures 46 and 47 it was expected that the

horizontal and diagonal velocity profiles would show some differences. However these velocity profiles were essentially identical for all three mixing stacks tested. Figure 51 is a sample single nozzle velocity profile comparison plot. As can be seen, the profiles are essentially identical. A slight misalignment of the mixing stack, or unequal pumping, etc., can be seen by the non-symmetrical plots. The induced secondary flow velocities are slightly higher in region 2 than in region 1 and the center peak velocity is offset slightly from the center of the stack.

All three mixing stacks tested produced nearly indentical PCD, MSD, and VTD results indicating that the mixing stack length (over the range tested) had little effect on the eductor system performance.

D. COMPARISON OF PERFORMANCE

The axial pressure distribution can be related to the completeness of mixing in the stack. As mixing occurs along the mixing stack, the decrease in momentum of the air is evidenced as a pressure rise. When the non-dimensional static pressure, PMS*, is plotted with distance along the stack, the rate of momentum exchange is indicated by the slope of the curve. A steep gradient represents an area of rapid momentum transfer and therefore, enhanced mixing. For optimum mixing the curve should approach atmospheric pressure tangentially at the mixing stack exit.

A comparison of axial pressure distributions and velocity profiles is shown in Figures 54 and 55. In both the four and single fluted nozzle configurations the slope of the axial pressure distribution curve is very steep at the entrance to the mixing stack when compared to the four straight nozzle system. This indicates a rapid transfer of momentum and enhanced mixing. However, the velocity traverse plots do not show a fully mixed profile.

The total perimeter of the single fluted nozzle is 27.9 inches compared to 23.3 inches for a four straight nozzle system (using the same size mixing stack). This produces a slightly larger area available for mixing in the case of the single fluted nozzle. The effective core area of the fluted nozzle is 4 square inches which is about 40% of the total area of the nozzle. The core area of a straight nozzle is 2.7 square inches which is 33% smaller than the fluted nozzle. The primary flow from the "fingers" of the fluted nozzle mixed very rapidly with the secondary flow as evidenced by the rapid rise in pressure at the entrance to the mixing stack. The larger core area of the fluted nozzle produced a jet that persisted down the length of the mixing stack. This large jet inhibited further mixing action between the primary and secondary flows producing the velocity profiles shown in Figures 54 and 55.

The rapid mixing of primary and secondary flows in the area of the "fingers" and the persistence of the jet from the relatively large core of the fluted nozzle indicates that perhaps a fluted nozzle with a reduced core area would be more effective.

VII. CONCLUSIONS

This research investigated the effects on the eductor system overall performance of utilizing four fluted primary nozzles and a single fluted primary nozzle. The conclusions from this investigation are as follows:

1. The system performance of the four fluted nozzle configuration is independent of the standoff distance between the nozzle exit and stack entrance.

2. The four fluted nozzle system produced essentially the same velocity profiles as the straight nozzles at the expense of a lower pumping coefficient and a degraded mixing stack axial pressure distribution.

3. System performance approached that of the straight nozzle system as the length of the fluted portion of the nozzles was reduced.

4. The one dimensional analysis used in the single fluted nozzle testing provides good correlation of data for Mach numbers from 55 to 125 percent of the design Mach number of 0.062.

5. The single fluted nozzle systems produced essentially the same pumping coefficient as the four staight nozzle system. The axial pressure distribution indicated rapid mixing near the entrance to the mixing stack, however the mixing action was significantly reduced beyond one-half diameter from the entrance to the stack.

VIII. RECOMMENDATIONS

Based on the findings of this investigation the following recommendations for future research are presented:

1. Test the multiple and single nozzle configurations using fluted nozzles with a reduced core area. Special attention should be given to mixing stack distribution data and exit velocity profiles for these systems.

2. With the data obtained from the above tests, select the nozzle geometry with the better overall performance and conduct tests using hot gas for the primary air flow. Correlate this data with the data obtained from cold flow testing.

DATA TAKEN ON: 30 APR 82
DATA TAKEN BY: J.W.BOYKIN

NOZZLE AM/AP AREA RATIO 2.50

COMMENTS:
FIRST RUN FLUTED NOZZLES

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.50

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 107.510 [IN2]
ATM. PRESSURE: 30.00 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.655	22.1	52.0	104.6	62.6	3.60	2.76	0.00	0.000	*******
2	0.650	21.9	52.0	105.2	62.8	4.30	1.85	0.00	12.566	*******
3	0.650	22.0	51.6	105.0	63.0	4.90	1.25	0.00	25.133	*******
4	0.640	22.0	51.8	105.2	63.2	5.50	0.66	0.00	50.265	*******
5	0.640	22.0	51.4	105.2	63.4	5.80	0.25	0.00	100.531	*******
6	0.640	22.0	52.0	105.2	63.6	5.90	0.14	0.00	150.796	*******
7	0.640	22.0	52.6	105.6	63.6	6.00	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3716	0.9256	0.4015	0.0000	3.7779	0.0000	180.65	72.27	72.27	0.062
2	0.1563	0.2525	0.9249	0.2730	0.1510	3.7578	0.5872	179.48	82.13	71.80	0.062
3	0.2560	0.1701	0.9256	0.1838	0.2474	3.7708	0.9652	179.77	88.90	71.92	0.062
4	0.3720	0.0901	0.9256	0.0973	0.3595	3.7701	1.4024	179.54	96.51	71.82	0.062
5	0.4576	0.0342	0.9260	0.0369	0.4424	3.7716	1.7259	179.43	102.17	71.78	0.062
6	0.5139	0.0192	0.9264	0.0207	0.4969	3.7694	1.9370	179.28	105.84	71.72	0.062
7	******	0.0014	0.9257	0.0015	******	3.7672		179.24	******	71.70	0.062

Table I. Four Fluted Nozzles (Full Run)

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.9256	0.0000	*******	3.778	*******	******
2	******	0.0000	0.9249	0.0000	*******	4.345	*******	******
3	******	0.0000	0.9256	0.0000	*******	4.736	*******	******
4	******	0.0000	0.9256	0.0000	*******	5.173	*******	******
5	******	0.0000	0.9260	0.0000	*******	5.498	*******	******
6	******	0.0000	0.9264	0.0000	*******	5.706	*******	******
7	******	0.0000	0.9257	0.0000	*******	******	*******	******

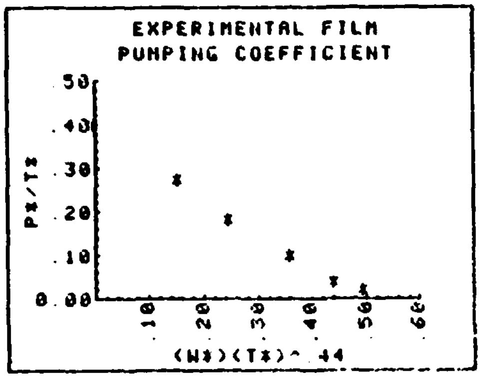
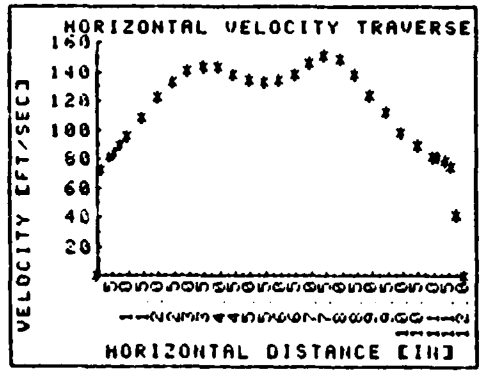


Table I. (contd) PCD

HORIZONTAL VELOCITY TRAVERSE AT BASE ROTATION OF 30 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	1.20	1.50	1.60	1.80	2.10	2.70
V[FT/SEC]:	0.00	72.69	81.27	83.93	89.02	96.16	109.03
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	3.40	4.00	4.50	4.70	4.70	4.30	4.10
V[FT/SEC]:	122.35	132.71	140.76	143.85	143.85	137.60	134.36
POSIT[IN]:	5.50	6.00	6.50	7.00	7.50	8.00	8.50
P[IN H2O]:	4.00	4.10	4.30	4.80	5.20	5.00	4.30
V[FT/SEC]:	132.71	134.36	137.60	145.38	151.31	148.37	137.60
POSIT[IN]:	9.00	9.50	10.00	10.50	11.00	11.20	11.40
P[IN H2O]:	3.50	2.90	2.20	1.80	1.50	1.50	1.40
V[FT/SEC]:	124.14	113.00	98.42	89.02	81.27	81.27	78.51
POSIT[IN]:	11.60	11.80	12.00				
P[IN H2O]:	1.30	0.40	0.00				
V[FT/SEC]:	75.66	41.97	0.00				



DIAGONAL VELOCITY TRAVERSE FOR BASE ROTATION OF 30 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	0.80	1.00	1.10	1.10	1.10	1.40
V[FT/SEC]:	0.00	59.35	66.35	69.59	69.59	69.59	78.51
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	1.80	2.50	3.30	4.00	4.40	4.40	4.10
V[FT/SEC]:	89.02	104.92	120.54	132.71	139.19	139.19	134.36
POSIT[IN]:	5.50	6.00	6.50	7.00	7.50	8.00	8.50
P[IN H2O]:	4.10	4.10	4.20	4.30	4.10	3.40	2.60
V[FT/SEC]:	134.36	134.36	135.99	137.60	134.36	122.35	106.99
POSIT[IN]:	9.00	9.50	10.00	10.50	11.00	11.20	11.40
P[IN H2O]:	2.10	1.50	1.40	1.30	1.00	1.00	0.90
V[FT/SEC]:	96.16	81.27	78.51	75.66	66.35	66.35	62.95
POSIT[IN]:	11.60	11.80	12.00				
P[IN H2O]:	0.70	0.40	0.00				
V[FT/SEC]:	55.52	41.97	0.00				

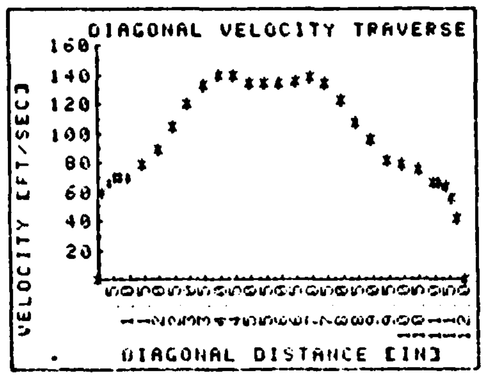


Table I. (contd) VTD

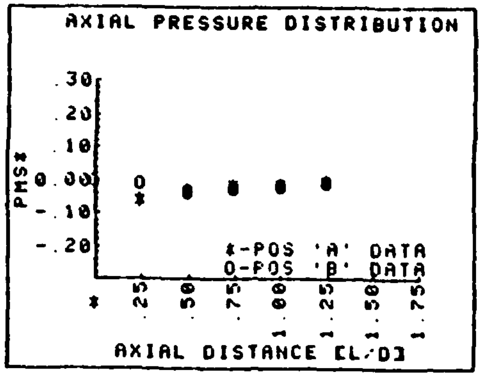
MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA:

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-2.740	30	-0.375
0.25	-0.440	28	-0.060
0.50	-0.200	30	-0.027
0.75	-0.110	30	-0.015
1.00	-0.110	30	-0.015
1.25	-0.030	30	-0.004

DIAGONAL (POSITION 'B') DATA:

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	0.000	0	0.000
0.25	-0.050	42	-0.007
0.50	-0.260	42	-0.036
0.75	-0.160	35	-0.022
1.00	-0.130	30	-0.018
1.25	-0.060	30	-0.008



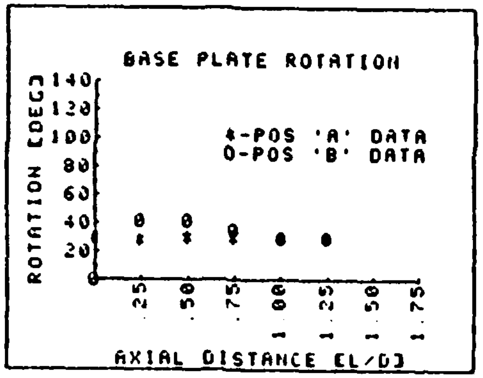


Table I. (contd) MSD

DATA TAKEN ON: 14 MAY 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
FULL RUN S/D=.5

MIXING STACK INFORMATION:
- LENGTH: 17.55 [IN]
- DIAMETER: 11.70 [IN]
- L/D RATIO: 1.50
- S/D RATIO: 0.50

PRIMARY NOZZLE INFORMATION:
- TILT ANGLE: 0.0 [DEG]
- ROTATION ANGLE: 0 [DEG]
- AREA PER NOZZLE: 10.752 [IN2]
- NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
- ORIFICE DIAMETER: 6.902 [IN]
- ORIFICE BETA: 0.497
- UPTAKE AREA: 107.510 [IN2]
- ATM. PRESSURE: 30.11 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.655	22.0	54.6	106.8	67.4	3.60	2.68	0.00	0.000	*******
2	0.650	22.0	55.4	107.8	68.0	4.30	1.80	0.00	12.566	*******
3	0.660	22.0	54.8	107.6	68.2	5.10	1.25	0.00	25.133	*******
4	0.660	22.0	55.0	107.8	68.2	5.50	0.65	0.00	50.265	*******
5	0.660	22.0	54.2	107.8	68.4	5.90	0.24	0.00	100.531	*******
6	0.655	22.0	54.8	108.0	68.4	6.10	0.12	0.00	150.796	*******
7	0.655	22.0	55.0	108.0	68.8	6.10	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3650	0.9304	0.3923	0.0000	3.7667	0.0000	180.12	72.05	72.05	0.062
2	0.1534	0.2460	0.9299	0.2646	0.1486	3.7638	0.5774	179.91	82.19	71.97	0.062
3	0.2555	0.1713	0.9305	0.1841	0.2475	3.7659	0.9622	179.71	88.93	71.89	0.062
4	0.3685	0.0893	0.9302	0.0960	0.3570	3.7652	1.3877	179.47	96.37	71.79	0.061
5	0.4475	0.0330	0.9306	0.0355	0.4335	3.7681	1.6861	179.43	101.65	71.78	0.061
6	0.4749	0.0165	0.9302	0.0178	0.4600	3.7660	1.7884	179.34	103.42	71.74	0.061
7	******	0.0014	0.9309	0.0015	******	3.7652		179.25	******	71.71	0.061

Table II. Four Fluted Nozzles (Symmetry Run)

TERTIARY BOX

N RUN	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM LBM/SEC	WT LBM/SEC	UE FT/SEC
1	******	0.0000	0.9304	0.0000	*******	3.767	*******	******
2	******	0.0000	0.9299	0.0000	*******	4.341	*******	******
3	******	0.0000	0.9305	0.0000	*******	4.728	*******	******
4	******	0.0000	0.9302	0.0000	*******	5.153	*******	******
5	******	0.0000	0.9306	0.0000	*******	5.454	*******	******
6	******	0.0000	0.9302	0.0000	*******	5.554	*******	******
7	******	0.0000	0.3309	0.0000	*******	******	*******	******

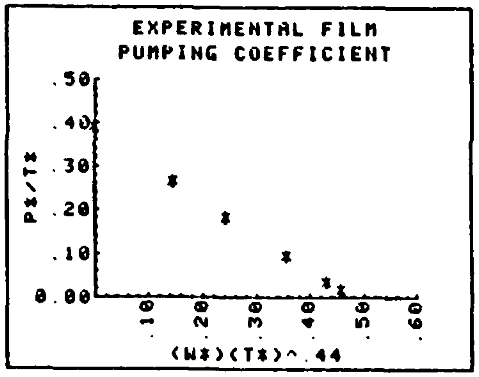
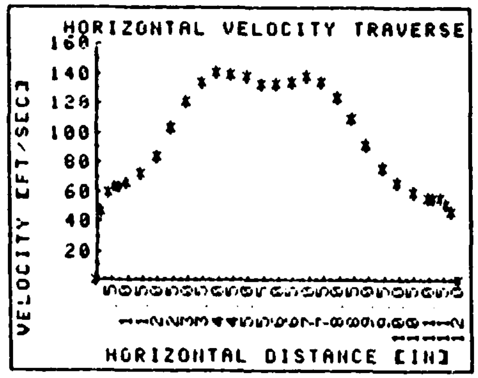


Table II. (contd) PCD

HORIZONTAL VELOCITY TRAVERSE AT BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	0.50	0.80	0.90	0.90	1.00	1.20
V[FT/SEC]:	0.00	47.07	59.53	63.15	63.15	66.56	72.91
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	1.60	2.40	3.30	4.10	4.50	4.40	4.30
V[FT/SEC]:	84.19	103.12	120.92	134.76	141.20	139.62	138.02
POSIT[IN]:	5.50	6.00	6.50	7.00	7.50	8.00	8.50
P[IN H2O]:	4.00	4.00	4.10	4.30	4.10	3.50	2.70
V[FT/SEC]:	133.12	133.12	134.78	138.02	134.78	124.53	109.37
POSIT[IN]:	9.00	9.50	10.00	10.50	11.00	11.20	11.40
P[IN H2O]:	1.90	1.30	1.00	0.80	0.70	0.70	0.70
V[FT/SEC]:	91.75	75.89	66.56	59.53	55.69	55.69	55.69
POSIT[IN]:	11.60	11.80	12.00				
P[IN H2O]:	0.60	0.50	0.00				
V[FT/SEC]:	51.56	47.07	0.00				



DIAGONAL VELOCITY TRAVERSE FOR BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	1.60	2.00	2.30	2.60	3.00	3.90
V[FT/SEC]:	0.00	84.19	94.13	100.95	107.33	115.29	131.45
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	4.90	5.60	6.00	5.80	5.20	4.60	4.20
V[FT/SEC]:	147.34	157.51	163.0'	160.30	151.78	142.76	136.41
POSIT[IN]:	5.50	6.00	6.50	7.00	7.50	8.00	8.50
P[IN H2O]:	4.00	4.10	4.50	5.00	5.40	5.60	5.40
V[FT/SEC]:	133.12	134.78	141.20	148.84	154.66	157.51	154.68
POSIT[IN]:	9.00	9.50	10.00	10.50	11.00	11.20	11.40
P[IN H2O]:	5.00	4.40	3.50	2.60	2.00	1.90	1.60
V[FT/SEC]:	148.84	139.62	124.53	107.33	94.13	91.75	84.19
POSIT[IN]:	11.60	11.80	12.00				
P[IN H2O]:	1.40	0.10	0.00				
V[FT/SEC]:	78.76	21.05	0.00				

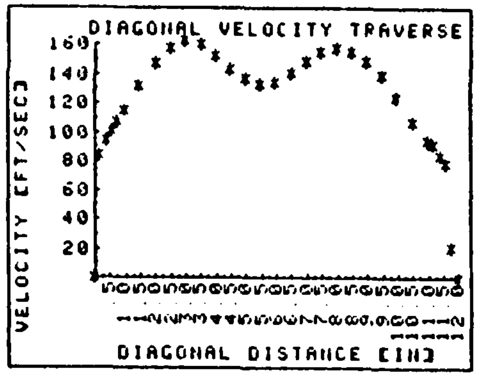
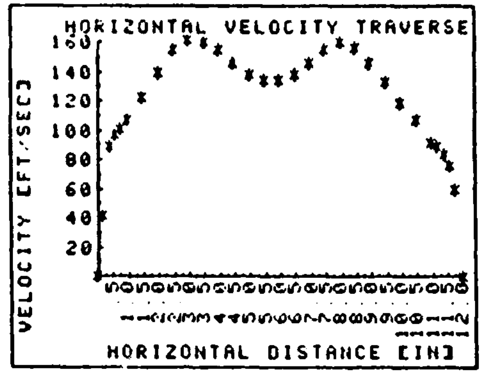


Table II. (contd) VTD

HORIZONTAL VELOCITY TRAVERSE AT BASE ROTATION OF 45 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	0.40	1.80	2.10	2.30	2.60	3.40
V[FT/SEC]:	0.00	42.10	89.30	96.46	100.95	107.33	122.73
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	4.40	5.40	5.90	5.80	5.40	4.80	4.30
V[FT/SEC]:	139.62	154.68	161.68	160.30	154.68	145.83	138.02
POSIT[IN]:	5.50	6.00	6.50	7.00	7.50	8.00	8.50
P[IN H2O]:	4.10	4.10	4.30	4.80	5.40	5.60	5.50
V[FT/SEC]:	134.78	134.78	138.02	145.83	154.68	160.30	156.10
POSIT[IN]:	9.00	9.50	10.00	10.50	11.00	11.20	11.40
P[IN H2O]:	4.80	4.00	3.20	2.60	1.90	1.80	1.60
V[FT/SEC]:	145.83	133.12	119.07	107.33	91.75	89.30	84.19
POSIT[IN]:	11.60	11.80	12.00				
P[IN H2O]:	1.30	0.80	0.00				
V[FT/SEC]:	75.89	59.53	0.00				



DIAGONAL VELOCITY TRAVERSE FOR BASE ROTATION OF 45 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	0.70	0.80	0.90	1.00	1.00	1.20
V[FT/SEC]:	0.00	55.69	59.53	63.15	66.56	66.56	72.91
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	1.60	2.40	3.10	3.90	4.30	4.30	4.10
V[FT/SEC]:	84.19	103.12	117.19	131.45	138.02	138.02	134.78
POSIT[IN]:	5.50	6.00	6.50	7.00	7.50	8.00	8.50
P[IN H2O]:	4.00	4.00	4.10	4.20	4.10	3.50	2.50
V[FT/SEC]:	133.12	133.12	134.78	136.41	134.78	124.53	105.24
POSIT[IN]:	9.00	9.50	10.00	10.50	11.00	11.20	11.40
P[IN H2O]:	1.70	1.10	0.80	0.70	0.70	0.70	0.60
V[FT/SEC]:	86.79	69.81	59.53	55.69	55.69	55.69	51.56
POSIT[IN]:	11.60	11.80	12.00				
P[IN H2O]:	0.50	0.10	0.00				
V[FT/SEC]:	47.07	21.05	0.00				

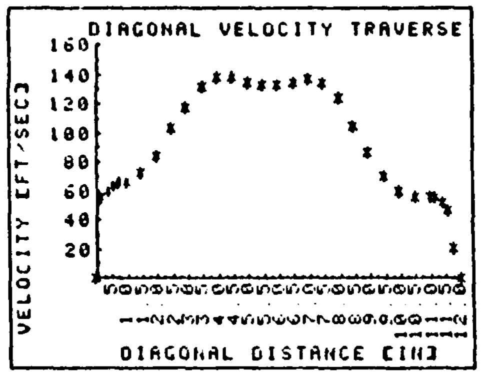


Table II. (contd) VTD

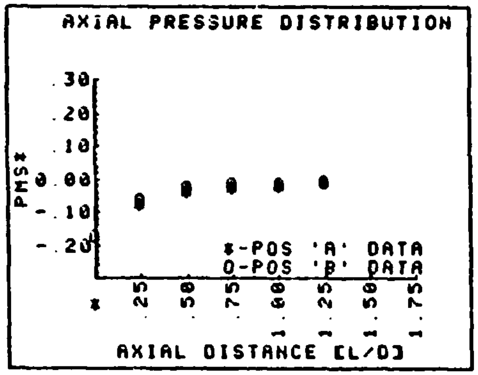
MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-2.750	30	-0.379
0.25	-0.550	43	-0.076
0.50	-0.280	45	-0.039
0.75	-0.160	0	-0.022
1.00	-0.140	0	-0.019
1.25	-0.040	0	-0.006

DIAGONAL (POSITION 'B') DATA

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-1.250	30	-0.172
0.25	-0.450	30	-0.062
0.50	-0.160	30	-0.022
0.75	-0.110	0	-0.015
1.00	-0.100	0	-0.014
1.25	-0.040	0	-0.006



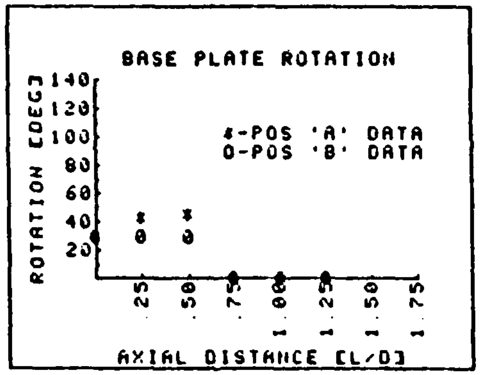


Table II. (contd) MSD

DATA TAKEN ON: 17 OCT 82
DATA TAKEN BY: J.W. BOYKIN   NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
S/D=.5 PCD RUN

MIXING STACK INFORMATION:		PRIMARY NOZZLE INFORMATION:		MISCELLANEOUS INFORMATION:	
LENGTH:	17.55 [IN]	TILT ANGLE:	0.0 [DEG]	ORIFICE DIAMETER:	6.902 [IN]
DIAMETER:	11.70 [IN]	ROTATION ANGLE:	0 [DEG]	ORIFICE BETA:	0.497
L/D RATIO:	1.50	AREA PER NOZZLE:	10.752 [IN2]	UPTAKE AREA:	107.510 [IN2]
S/D RATIO:	0.50	NUMBER OF NOZZLES:	4	ATM. PRESSURE:	29.95 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.645	22.0	57.2	109.8	65.6	3.60	2.64	0.00	0.000	*******
2	0.640	22.0	57.0	109.8	65.6	4.30	1.77	0.00	12.566	*******
3	0.640	21.9	56.8	109.8	66.0	4.90	1.25	0.00	25.133	*******
4	0.640	22.0	56.8	109.8	65.8	5.40	0.65	0.00	50.265	*******
5	0.640	22.0	57.0	110.0	66.0	5.90	0.23	0.00	100.531	*******
6	0.640	22.0	56.8	110.0	66.0	6.00	0.13	0.00	150.796	*******
7	0.640	22.0	57.0	110.0	66.0	6.10	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3564	0.9224	0.3864	0.0000	3.7472	0.0000	181.09	72.44	72.44	0.062
2	0.1527	0.2399	0.9224	0.2601	0.1474	3.7480	0.5723	180.74	82.44	72.30	0.062
3	0.2571	0.1707	0.9231	0.1849	0.2482	3.7402	0.9616	180.13	89.11	72.06	0.062
4	0.3700	0.0886	0.9227	0.0960	0.3572	3.7487	1.3871	180.27	96.70	72.12	0.062
5	0.4402	0.0314	0.9228	0.0340	0.4249	3.7480	1.6500	180.12	101.30	72.05	0.062
6	0.4964	0.0178	0.9228	0.0192	0.4791	3.7487	1.8607	180.11	105.04	72.05	0.062
7	******	0.0014	0.9228	0.0015	******	3.7460	.	180.02	******	72.01	0.062

Table III. S/D = 0.50

TERTIARY BOX

N RUN	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM LBM/SEC	WT LBM/SEC	UE FT/SEC
1	******	0.0000	0.9224	0.0000	*******	3.747	*******	******
2	******	0.0000	0.9224	0.0000	*******	4.320	*******	******
3	******	0.0000	0.9231	0.0000	*******	4.702	*******	******
4	******	0.0000	0.9227	0.0000	*******	5.136	*******	******
5	******	0.0000	0.9228	0.0000	*******	5.396	*******	******
6	******	0.0000	0.9228	0.0000	*******	5.609	*******	******
7	******	0.0000	0.9228	0.0000	*******	******	*******	******

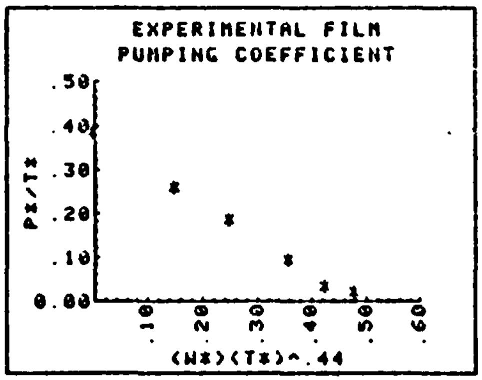


Table III. (contd) PCD

DATA TAKEN ON: 17 OCT 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
S/D=.45 PCD RUN

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.45

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 107.518 [IN2]
ATM. PRESSURE: 29.95 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.645	22.0	56.6	108.6	65.8	3.50	2.68	0.00	0.000	*******
2	0.640	22.0	56.6	109.8	65.8	4.30	1.78	0.00	12.566	*******
3	0.640	22.0	56.9	109.6	65.8	4.90	1.26	0.00	25.133	*******
4	0.640	22.0	57.0	109.8	65.8	5.40	0.65	0.00	50.265	*******
5	0.640	22.0	57.6	110.0	65.8	5.80	0.24	0.00	100.531	*******
6	0.640	22.0	57.0	110.0	65.8	6.00	0.13	0.00	150.796	*******
7	0.640	22.0	57.0	110.2	66.0	6.10	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3630	0.9247	0.3925	0.0000	3.7494	0.0000	180.83	72.34	72.34	0.062
2	0.1531	0.2411	0.9227	0.2613	0.1477	3.7494	0.5739	180.81	82.50	72.33	0.062
3	0.2576	0.1713	0.9231	0.1856	0.2487	3.7487	0.9657	180.48	89.31	72.20	0.062
4	0.3701	0.0886	0.9227	0.0960	0.3572	3.7480	1.3871	180.24	96.68	72.10	0.062
5	0.4498	0.0328	0.9224	0.0355	0.4341	3.7480	1.6858	180.12	101.93	72.05	0.062
6	0.4965	0.0178	0.9224	0.0192	0.4792	3.7480	1.8610	180.07	105.02	72.04	0.062
7	******	0.0014	0.9224	0.0015	******	3.7480		180.08	******	72.04	0.062

Table IV. S/D = 0.45

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.9247	0.0000	*******	3.749	*******	******
2	******	0.0000	0.9227	0.0000	*******	4.323	*******	******
3	******	0.0000	0.9231	0.0000	*******	4.714	*******	******
4	******	0.0000	0.9227	0.0000	*******	5.135	*******	******
5	******	0.0000	0.9224	0.0000	*******	5.434	*******	******
6	******	0.0000	0.9224	0.0000	*******	5.609	*******	******
7	******	0.0000	0.9224	0.0000	*******	******	*******	******

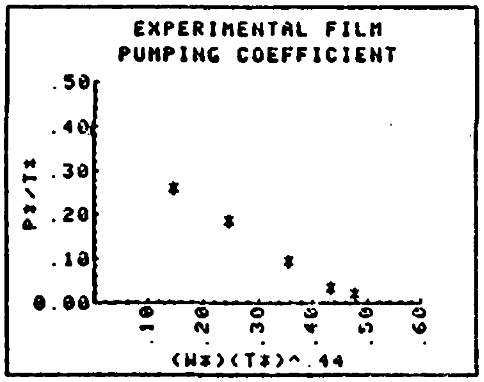


Table IV. (contd) PCD

DATA TAKEN ON: 17 OCT 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
S/D=.4 PCD RUN

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.40

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 107.510 [IN2]
ATM. PRESSURE: 29.95 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES	F		IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.640	22.0	56.4	109.2	65.8	3.50	2.69	0.00	0.000	*******
2	0.635	22.0	56.4	109.6	65.8	4.30	1.80	0.00	12.566	*******
3	0.640	22.0	57.0	109.8	66.0	4.90	1.20	0.00	25.133	*******
4	0.640	22.0	56.2	109.8	66.0	5.40	0.68	0.00	50.265	*******
5	0.640	22.0	56.8	109.8	66.0	5.90	0.24	0.00	100.531	*******
6	0.640	22.0	56.2	109.8	66.0	6.00	0.13	0.00	150.796	*******
7	0.640	22.0	56.8	110.0	66.0	6.10	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3634	0.9237	0.3934	0.0000	3.7502	0.0000	181.06	72.43	72.43	0.062
2	0.1539	0.2439	0.9231	0.2642	0.1486	3.7502	0.5771	180.79	82.55	72.32	0.062
3	0.2596	0.1740	0.9231	0.1885	0.2507	3.7480	0.9731	180.52	89.46	72.21	0.062
4	0.3782	0.0926	0.9231	0.1003	0.3651	3.7509	1.4185	180.39	97.31	72.16	0.062
5	0.4496	0.0328	0.9231	0.0355	0.4341	3.7487	1.6855	180.09	101.92	72.04	0.062
6	0.4961	0.0177	0.9231	0.0192	0.4769	3.7509	1.8607	180.15	105.05	72.07	0.062
7	******	0.0014	0.9228	0.0015	******	3.7487		180.05	******	72.03	0.062

Table V. S/D = 0.40

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.9237	0.0000	*******	3.750	*******	******
2	******	0.0000	0.9231	0.0000	*******	4.327	*******	******
3	******	0.0000	0.9231	0.0000	*******	4.721	*******	******
4	******	0.0000	0.9231	0.0000	*******	5.169	*******	******
5	******	0.0000	0.9231	0.0000	*******	5.434	*******	******
6	******	0.0000	0.9231	0.0000	*******	5.612	*******	******
7	******	0.0000	0.9228	0.0000	*******	******	*******	******

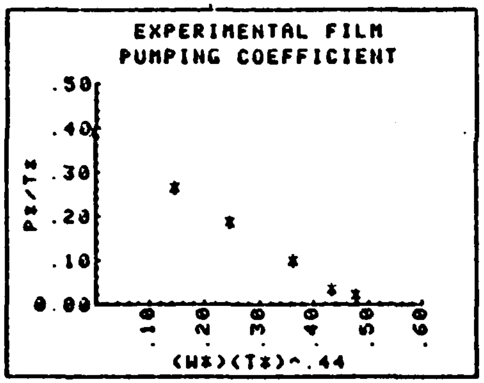


Table V. (contd) PCD

DATA TAKEN ON: 17 OCT 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
S/D=.35 PCD RUN

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.35

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 107.510 [IN2]
ATM. PRESSURE: 29.95 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.640	22.0	56.0	109.6	65.8	3.50	2.73	0.00	0.000	*******
2	0.640	22.0	56.2	109.6	66.0	4.40	1.83	0.00	12.566	*******
3	0.640	22.0	56.2	109.6	66.0	4.90	1.25	0.00	25.133	*******
4	0.640	22.0	55.8	109.8	66.4	5.40	0.67	0.00	50.265	*******
5	0.640	22.0	56.2	109.8	66.2	5.80	0.25	0.00	100.531	*******
6	0.640	22.0	56.0	109.6	66.4	6.00	0.12	0.00	150.796	*******
7	0.645	22.1	56.0	109.6	66.2	6.10	0.02	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0009	0.3679	0.9231	0.3986	0.0000	3.7516	0.0000	181.20	72.52	72.52	0.062
2	0.1551	0.2479	0.9234	0.2685	0.1498	3.7509	0.5817	180.84	82.65	72.34	0.062
3	0.2564	0.1698	0.9234	0.1839	0.2475	3.7509	0.9616	180.58	89.29	72.24	0.062
4	0.3751	0.0912	0.9238	0.0988	0.3622	3.7523	1.4075	180.46	97.16	72.19	0.062
5	0.4585	0.0341	0.9234	0.0370	0.4427	3.7509	1.7199	180.20	102.59	72.09	0.062
6	0.4763	0.0164	0.9241	0.0177	0.4601	3.7516	1.7870	180.11	103.76	72.05	0.062
7	******	0.0027	0.9238	0.0029	******	3.7601		180.48	******	72.20	0.062

Table VI. S/D = 0.35

TERTIARY BOX

N RUN	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM LBM/SEC	WT LBM/SEC	UE FT/SEC
1	******	0.0000	0.9231	0.0000	*******	3.752	*******	******
2	******	0.0000	0.9234	0.0000	*******	4.333	*******	******
3	******	0.0000	0.9234	0.0000	*******	4.713	*******	******
4	******	0.0000	0.9238	0.0000	*******	5.160	*******	******
5	******	0.0000	0.9234	0.0000	*******	5.471	*******	******
6	******	0.0000	0.9241	0.0000	*******	5.539	*******	******
7	******	0.0000	0.9238	0.0000	*******	******	*******	******

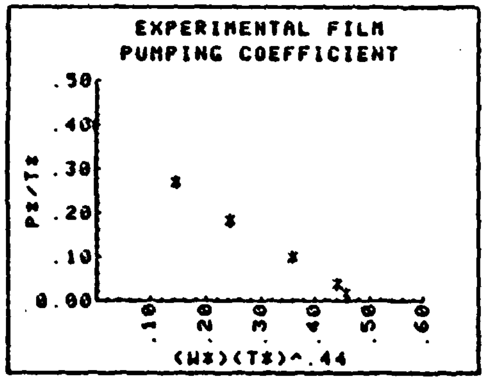


Table VI. (contd) PCD

DATA TAKEN ON: 17 OCT 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
S/D=.3 PCD RUN

MIXING STACK INFORMATION:		PRIMARY NOZZLE INFORMATION:		MISCELLANEOUS INFORMATION:	
LENGTH:	17.55 [IN]	TILT ANGLE:	0.0 [DEG]	ORIFICE DIAMETER:	6.902 [IN]
DIAMETER:	11.70 [IN]	ROTATION ANGLE:	0 [DEG]	ORIFICE BETA:	0.497
L/D RATIO:	1.50	AREA PER NOZZLE:	10.752 [IN2]	UPTAKE AREA:	107.510 [IN2]
S/D RATIO:	0.30	NUMBER OF NOZZLES:	4	ATM. PRESSURE:	29.95 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES	F		IN OF H2O			SQUAPE INCHES	SQUARE INCHES
1	0.640	22.0	56.2	107.4	66.0	3.50	2.85	0.00	0.000	*******
2	0.645	22.0	56.0	108.4	65.8	4.40	1.83	0.00	12.566	*******
3	0.645	22.0	56.2	108.8	65.8	4.90	1.25	0.00	25.133	*******
4	0.640	22.0	56.4	109.4	66.0	5.40	0.68	0.00	50.265	*******
5	0.640	22.0	56.6	109.4	66.0	5.80	0.26	0.00	100.531	*******
6	0.640	22.0	56.4	109.6	66.0	5.90	0.13	0.00	150.796	*******
7	0.640	22.0	56.6	109.8	66.0	6.00	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3872	0.9270	0.4176	0.0000	3.7509	0.0000	180.60	72.24	72.24	0.062
2	0.1551	0.2488	0.9250	0.2690	0.1499	3.7516	0.5819	180.49	82.51	72.20	0.062
3	0.2564	0.1702	0.9244	0.1842	0.2477	3.7509	0.9618	180.33	89.18	72.14	0.062
4	0.3783	0.0927	0.9237	0.1004	0.3653	3.7502	1.4165	180.23	97.25	72.10	0.062
5	0.4679	0.0355	0.9237	0.0385	0.4518	3.7494	1.7543	180.01	103.11	72.01	0.062
6	0.4962	0.0178	0.9234	0.0192	0.4791	3.7502	1.8637	180.05	105.01	72.03	0.062
7	******	0.0014	0.9231	0.0015	******	3.7494	-	180.02	******	72.02	0.062

Table VII. S/D = 0.30

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.9270	0.0000	*******	3.751	*******	******
2	******	0.0000	0.9250	0.0000	*******	4.333	*******	******
3	******	0.0000	0.9244	0.0000	*******	4.713	*******	******
4	******	0.0000	0.9237	0.0000	*******	5.169	*******	******
5	******	0.0000	0.9237	0.0000	*******	5.504	*******	******
6	******	0.0000	0.9234	0.0000	*******	5.611	*******	******
7	******	0.0000	0.9231	0.0000	*******	******	*******	******

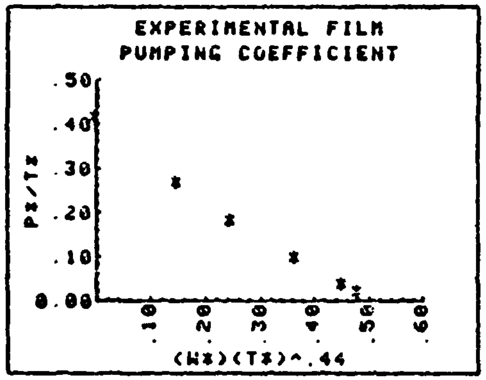


Table VII. (contd) PCD

DATA TAKEN ON: 14 MAY 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
FULL RUN S/D= 25

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.25

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 107.510 [IN2]
ATM. PRESSURE: 30.11 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.655	22.0	53.2	104.8	66.2	3.50	2.85	0.00	0.000	*******
2	0.655	22.0	52.6	105.0	66.6	4.30	1.88	0.00	12.566	*******
3	0.660	22.0	53.2	106.2	66.8	4.80	1.30	0.00	25.133	*******
4	0.660	22.0	52.8	106.4	66.8	5.50	0.74	0.00	50.265	*******
5	0.660	22.0	53.2	106.8	67.0	5.80	0.29	0.00	100.531	*******
6	0.660	22.0	53.0	106.8	67.0	5.90	0.13	0.00	150.796	*******
7	0.660	22.0	52.8	106.8	67.0	6.00	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3886	0.9316	0.4172	0.0000	3.7718	0.0000	179.80	71.93	71.93	0.062
2	0.1566	0.2566	0.9307	0.2757	0.1517	3.7740	0.5909	179.80	82.36	71.93	0.062
3	0.2605	0.1780	0.9304	0.1913	0.2524	3.7718	0.9825	179.56	89.18	71.83	0.062
4	0.3929	0.1014	0.9300	0.1091	0.3806	3.7733	1.4826	179.45	97.97	71.79	0.062
5	0.4920	0.0398	0.9297	0.0428	0.4765	3.7718	1.8559	179.31	104.52	71.73	0.061
6	0.4941	0.0179	0.9297	0.0192	0.4785	3.7725	1.8639	179.27	104.65	71.72	0.061
7	******	0.0014	0.9297	0.0015	******	3.7733		179.26	******	71.71	0.061

Table VIII. S/D = 0.25

TERTIARY BOX

N RUN	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM LBM/SEC	WT LBM/SEC	UE FT/SEC
1	******	0.0000	0.9316	0.0000	*******	3.772	*******	******
2	******	0.0000	0.9307	0.0000	*******	4.365	*******	******
3	******	0.0000	0.9304	0.0000	*******	4.754	*******	******
4	******	0.0000	0.9300	0.0000	*******	5.256	*******	******
5	******	0.0000	0.9297	0.0000	*******	5.628	*******	******
6	******	0.0000	0.9297	0.0000	*******	5.636	*******	******
7	******	0.0000	0.9297	0.0000	*******	******	*******	******

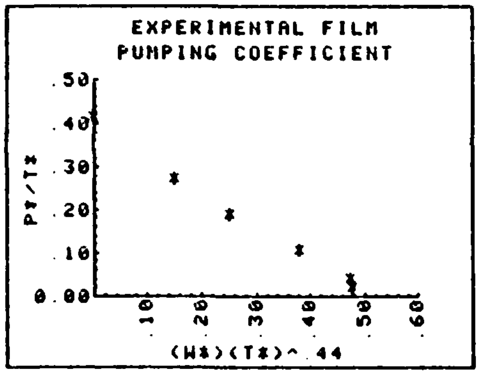


Table VIII. (contd) PCD

DATA TAKEN ON: 22 MAY 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
PCD RUN S/D=.125

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.13

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 107.510 [IN2]
ATM PRESSURE: 29.95 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.650	22.0	51.6	102.2	60.6	3.50	2.80	0.00	0.000	*******
2	0.650	22.0	51.8	103.0	60.8	4.30	1.85	0.00	12.566	*******
3	0.650	22.0	51.6	103.6	60.8	4.70	1.32	0.00	25.133	*******
4	0.650	22.0	51.6	103.8	60.8	5.20	1.66	0.00	50.265	*******
5	0.645	21.9	51.4	104.4	61.2	5.50	0.25	0.00	100.531	*******
6	0.645	22.0	51.6	104.4	61.4	5.50	0.12	0.00	150.756	*******
7	0.645	21.8	51.6	104.6	61.4	5.60	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3801	0.9260	0.4105	0.0000	3.7677	0.0000	179.72	71.89	71.89	0.062
2	0.1561	0.2518	0.9250	0.2722	0.1508	3.7669	0.5878	179.52	82.13	71.81	0.062
3	0.2636	0.1797	0.9240	0.1945	0.2545	3.7677	0.9931	179.51	89.24	71.81	0.062
4	0.5912	0.2254	0.9237	0.2441	0.5709	3.7677	2.2274	179.72	110.59	71.90	0.062
5	0.4596	0.0343	0.9234	0.0371	0.4438	3.7599	1.7281	178.92	101.93	71.57	0.061
6	0.4766	0.0164	0.9238	0.0178	0.4602	3.7677	1.7956	179.23	103.25	71.70	0.062
7	******	0.0014	0.9234	0.0015	******	3.7505		178.43	******	71.38	0.061

Table IX. S/D = 0.125

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.9260	0.0000	*******	3.768	*******	******
2	******	0.0000	0.9250	0.0000	*******	4.355	*******	******
3	******	0.0000	0.9240	0.0000	*******	4.761	*******	******
4	******	0.0000	0.9237	0.0000	*******	5.995	*******	******
5	******	0.0000	0.9234	0.0000	*******	5.488	*******	******
6	******	0.0000	0.9238	0.0000	*******	5.563	*******	******
7	******	0.0000	0.9234	0.0000	*******	******	*******	******

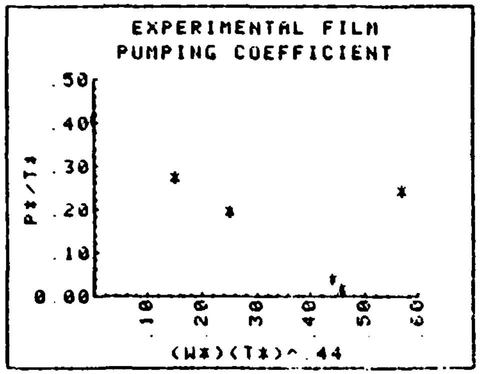


Table IX. (contd PCD)

DATA TAKEN ON: 24 OCT 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
3/4 LENGTH FLUTED NOZZLES

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.40

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 107.510 [IN2]
ATM. PRESSURE: 29.90 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.645	22.0	63.2	111.0	66.6	3.60	3.00	0.00	0.000	*******
2	0.650	22.0	63.4	113.6	66.8	4.60	2.03	0.00	12.566	*******
3	0.645	22.0	63.2	114.0	67.0	5.20	1.38	0.00	25.133	*******
4	0.640	22.0	63.2	115.0	68.0	5.80	0.74	0.00	50.265	*******
5	0.645	22.0	63.6	115.2	68.2	5.90	0.27	0.00	100.531	*******
6	0.640	22.0	63.6	115.6	68.4	6.40	0.14	0.00	150.796	*******
7	0.650	22.0	63.2	115.6	68.6	6.60	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.4069	0.9209	0.4418	0.0000	3.7226	0.0000	180.99	72.40	72.40	0.062
2	0.1644	0.2751	0.9184	0.2996	0.1583	3.7218	0.6117	181.09	83.32	72.44	0.062
3	0.2709	0.1874	0.9181	0.2041	0.2609	3.7226	1.0086	180.96	90.34	72.39	0.062
4	0.3964	0.1006	0.9182	0.1096	0.3818	3.7226	1.4757	180.99	98.71	72.40	0.062
5	0.4790	0.0368	0.9182	0.0401	0.4614	3.7211	1.7825	180.78	104.10	72.32	0.062
6	0.5173	0.0191	0.9180	0.0208	0.4982	3.7212	1.9249	180.85	106.60	72.35	0.062
7	******	0.0014	0.9183	0.0015	******	3.7223		180.86	******	72.35	0.062

Table X. 3/4 Length Fluted Nozzles (Partial Run)

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.9209	0.0000	*******	3.723	*******	******
2	******	0.0000	0.9184	0.0000	*******	4.334	*******	******
3	******	0.0000	0.9181	0.0000	*******	4.731	*******	******
4	******	0.0000	0.9182	0.0000	*******	5.198	*******	******
5	******	0.0000	0.9182	0.0000	*******	5.504	*******	******
6	******	0.0000	0.9180	0.0000	*******	5.646	*******	******
7	******	0.0000	0.9183	0.0000	*******	******	*******	******

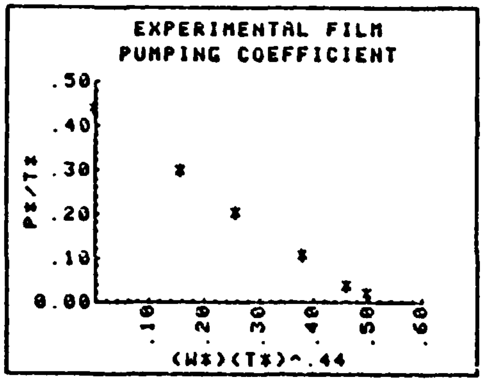


Table X. (contd) PCD

DATA TAKEN ON: 27 OCT 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.50

COMMENTS:
3/4 LENGTH FLUTED FULL RUN

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.40

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 107.510 [IN2]
ATM. PRESSURE: 30.12 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.650	22.0	52.6	105.0	60.2	3.60	3.13	0.00	0.000	*******
2	0.650	22.0	52.8	105.4	60.4	4.60	2.04	0.00	12.566	*******
3	0.645	22.0	52.8	105.4	60.8	5.20	1.40	0.00	25.133	*******
4	0.645	22.0	52.2	105.4	60.8	5.90	0.74	0.00	50.265	*******
5	0.650	22.0	52.4	105.4	61.0	6.30	0.22	0.00	100.531	*******
6	0.650	22.0	52.6	105.4	61.0	6.50	0.14	0.00	150.796	*******
7	0.650	22.0	52.4	105.4	61.0	6.60	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.4206	0.9207	0.4568	0.0000	3.7747	0.0000	180.07	72.03	72.03	0.062
2	0.1641	0.2754	0.9204	0.2992	0.1582	3.7739	0.6193	179.60	82.68	71.88	0.062
3	0.2718	0.1897	0.9211	0.2060	0.2621	3.7740	1.0257	179.40	89.67	71.77	0.062
4	0.3949	0.1005	0.9211	0.1091	0.3805	3.7762	1.4914	179.21	97.72	71.69	0.062
5	0.4307	0.0300	0.9214	0.0325	0.4155	3.7754	1.6260	178.55	99.98	71.59	0.061
6	0.5155	0.0191	0.9214	0.0207	0.4972	3.7747	1.9457	178.88	105.53	71.56	0.061
7	******	0.0014	0.9214	0.0015	******	3.7754		178.86	******	71.55	0.061

Table XI. 3/4 Length Fluted Nozzles (Full Run)

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.9207	0.0000	*******	3.775	*******	******
2	******	0.0000	0.9204	0.0000	*******	4.393	*******	******
3	******	0.0000	0.9211	0.0000	*******	4.800	*******	******
4	******	0.0000	0.9211	0.0000	*******	5.260	*******	******
5	******	0.0000	0.9214	0.0000	*******	5.401	*******	******
6	******	0.0000	0.9214	0.0000	*******	5.720	*******	******
7	******	0.0000	0.9214	0.0000	*******	******	*******	******

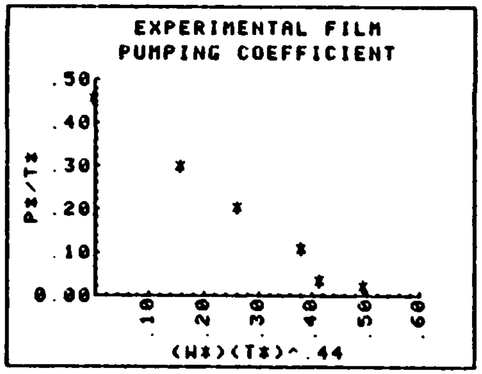
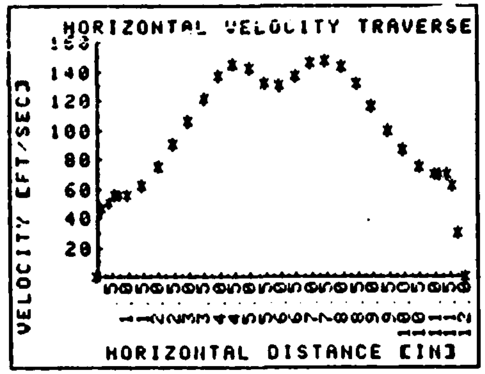


Table XI. (contd) PCD

HORIZONTAL VELOCITY TRAVERSE AT BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
PE[IN H2O]:	0.00	0.50	0.60	0.70	0.70	0.70	0.90
VE[FT/SEC]:	0.00	46.71	51.17	55.27	55.27	55.27	62.67
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
PE[IN H2O]:	1.30	1.90	2.60	3.40	4.30	4.80	4.60
VE[FT/SEC]:	75.32	91.85	106.51	121.80	136.98	144.72	141.68
POSIT[IN]:	5.50	6.00	6.50	7.00	7.50	8.00	8.50
PE[IN H2O]:	4.00	3.90	4.30	4.90	5.00	4.70	4.00
VE[FT/SEC]:	132.12	130.45	136.98	146.22	147.71	143.21	132.12
POSIT[IN]:	9.00	9.50	10.00	10.50	11.00	11.20	11.40
PE[IN H2O]:	3.10	2.30	1.70	1.30	1.10	1.10	1.10
VE[FT/SEC]:	116.31	100.18	86.13	75.32	69.28	69.28	69.28
POSIT[IN]:	11.60	11.80	12.00				
PE[IN H2O]:	0.90	0.20	0.00				
VE[FT/SEC]:	62.67	29.54	0.00				



DIAGONAL VELOCITY TRAVERSE FOR BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
PE[IN H2O]:	0.00	0.70	1.30	1.60	1.70	2.00	2.70
VE[FT/SEC]:	0.00	55.27	75.32	83.56	86.13	93.42	108.54
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
PE[IN H2O]:	3.90	5.00	6.20	6.80	6.30	5.20	4.30
VE[FT/SEC]:	130.45	147.71	164.48	172.26	165.80	150.63	136.98
POSIT[IN]:	5.50	6.00	6.50	7.00	7.50	8.00	8.50
PE[IN H2O]:	3.90	3.90	4.00	4.40	5.00	5.60	5.70
VE[FT/SEC]:	130.45	130.45	132.12	138.56	147.71	156.32	157.71
POSIT[IN]:	9.00	9.50	10.00	10.50	11.00	11.20	11.40
PE[IN H2O]:	5.40	4.00	4.00	3.00	2.00	1.80	1.60
VE[FT/SEC]:	153.50	144.72	132.12	114.41	93.42	88.63	83.56
POSIT[IN]:	11.60	11.80	12.00				
PE[IN H2O]:	1.30	0.70	0.00				
VE[FT/SEC]:	75.32	55.27	0.00				

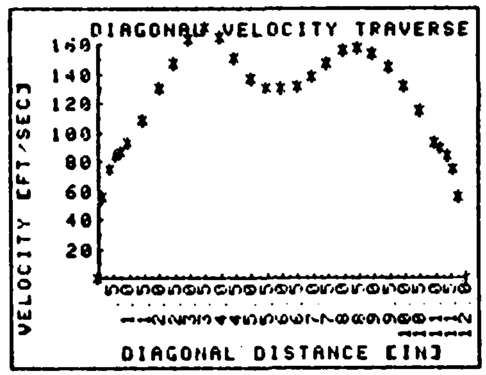
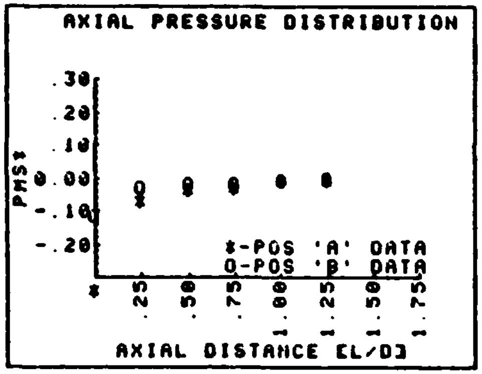


Table XI. (contd) VTD

MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA:				DIAGONAL (POSITION 'B') DATA:			
X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*	X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-2.480	40	-0.339	0.00	-0.030	30	-0.113
0.25	-0.510	0	-0.070	0.25	-0.210	0	-0.029
0.50	-0.260	0	-0.035	0.50	-0.140	0	-0.019
0.75	-0.210	0	-0.029	0.75	-0.140	0	-0.019
1.00	-0.070	0	-0.010	1.00	-0.070	0	-0.010
1.25	-0.070	0	-0.010	1.25	-0.010	0	-0.001



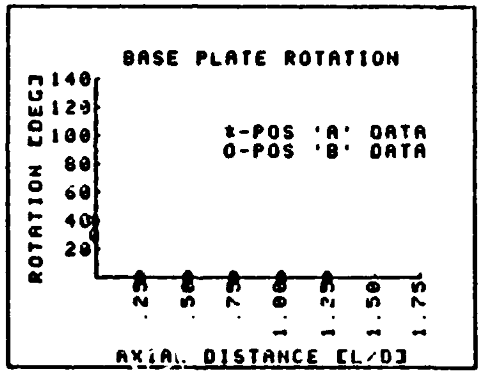


Table XI. (contd) MSD

DATA TAKEN ON: 13 NOV 82
DATA TAKEN BY: J W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2 64

COMMENTS:
1/2 LENGTH FLUTED

MIXING STACK INFORMATION:
LENGTH: 17.55 [IN]
DIAMETER: 11.70 [IN]
L/D RATIO: 1.50
S/D RATIO: 0.40

PRIMARY NOZZLE INFORMATION
TILT ANGLE 0 0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10 162 [IN2]
NUMBER OF NOZZLES: 4

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6 982 [IN]
ORIFICE BETA: 0 497
UPTAKE AREA: 107.510 [IN2]
ATM. PRESSURE: 29.80 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0 670	22 0	53.2	105.0	59.4	3 80	3.28	0.00	0 000	*******
2	0 665	22 0	53.0	105.2	58 6	4 60	2 18	0 00	12 566	*******
3	0.665	22.0	52.8	105.2	59.0	5 60	1.48	0.00	25.133	*******
4	0.665	22 0	52 4	105 2	59.2	6 10	0.80	0.00	50.265	*******
5	0.660	21.9	52.2	105.0	59 2	6.60	0.31	0.00	100.531	*******
6	0.660	21.9	51.8	105.0	59.2	6.70	0.15	0.00	150.796	*******
7	0.660	21.9	51.4	104.8	59 6	6.80	0.01	0 00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0 3925	0.9175	0 4278	0 0000	3.7523	0 0000	191 51	72 41	72.41	0 062
2	0.1700	0.2621	0.9175	0.2856	0 1636	3 7530	0 6379	191 09	87 45	72.25	0.062
3	0.2799	0.1786	0.9182	0.1945	0.2696	3.7537	1.0508	190.80	90.61	72.14	0.062
4	0.4114	0.0958	0.9186	0 1054	0 3963	3.7552	1 5448	190.55	99 21	72.05	0 062
5	0 5132	0 0378	0.9189	0 0411	0 4945	3 7474	1 9232	189 56	105.61	71.78	0.062
6	0.5353	0.0183	0.9189	0.0199	0 5157	3.7489	2 0067	189.86	107.07	71.78	0 062
7	******	0.0012	0.9199	0.0013	******	3.7504		189 80	******	71.76	0 062

Table XII. 1/2 Length Fluted Nozzles (Full Run)

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.9175	0.0000	*******	3.752	*******	******
2	******	0.0000	0.9175	0.0000	*******	4.391	*******	******
3	******	0.0000	0.9182	0.0000	*******	4.805	*******	******
4	******	0.0000	0.9186	0.0000	*******	5.300	*******	******
5	******	0.0000	0.9189	0.0000	*******	5.671	*******	******
6	******	0.0000	0.9189	0.0000	*******	5.756	*******	******
7	******	0.0000	0.9139	0.0000	*******	******	*******	******

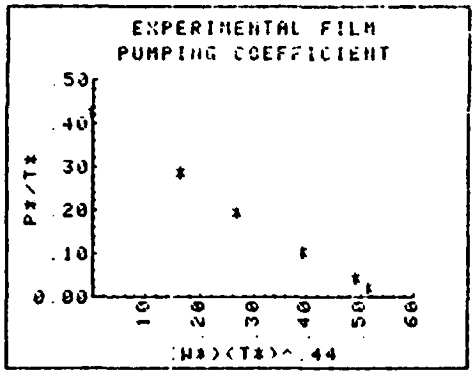
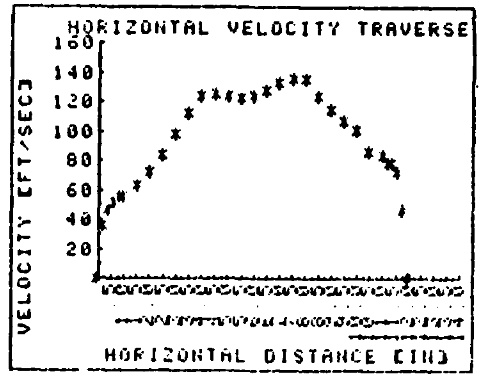


Table XII. (contd) PCD

HORIZONTAL VELOCITY TRAVERSE AT			BASE ROTATION OF 00 DEGREES			
POSIT[IN]: 0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]: 0.00	0.30	0.50	0.60	0.70	0.70	0.50
V[FT/SEC]: 0.00	36.33	46.90	51.37	55.49	55.49	62.92
POSIT[IN]: 2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]: 1.20	1.60	2.20	2.90	3.50	3.60	3.50
V[FT/SEC]: 72.65	83.89	98.37	112.94	124.08	125.84	124.08
POSIT[IN]: 5.50	6.00	6.50	7.00	7.50	8.00	8.50
P[IN H2O]: 3.40	3.50	3.70	4.00	4.20	4.20	3.50
V[FT/SEC]: 122.29	124.08	127.57	132.64	135.92	135.92	124.08
POSIT[IN]: 9.00	9.50	10.00	10.50	11.00	11.20	11.40
P[IN H2O]: 3.00	2.60	2.30	1.70	1.60	1.40	1.40
V[FT/SEC]: 114.87	106.94	100.58	86.47	83.89	78.47	78.47
POSIT[IN]: 11.60	11.80	12.00				
P[IN H2O]: 1.20	0.50	0.00				
V[FT/SEC]: 72.65	46.90	0.00				



DIAGONAL VELOCITY TRAVERSE FOR			BASE ROTATION OF 00 DEGREES			
POSIT[IN]: 0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]: 0.00	1.40	2.00	2.20	2.70	3.00	4.30
V[FT/SEC]: 0.00	79.47	93.79	98.37	108.98	114.97	137.53
POSIT[IN]: 2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]: 5.70	6.70	6.70	6.00	5.20	4.20	3.80
V[FT/SEC]: 158.34	171.67	171.67	162.43	148.30	135.92	129.29
POSIT[IN]: 5.50	6.00	6.50	7.00	7.50	8.00	8.50
P[IN H2O]: 3.50	3.40	3.50	3.70	4.20	4.70	5.00
V[FT/SEC]: 124.08	122.29	124.08	127.57	135.92	143.78	148.30
POSIT[IN]: 9.00	9.50	10.00	10.50	11.00	11.20	11.40
P[IN H2O]: 5.30	5.10	4.20	3.00	2.00	1.60	1.30
V[FT/SEC]: 152.68	149.78	135.92	114.87	93.79	83.89	75.62
POSIT[IN]: 11.60	11.80	12.00				
P[IN H2O]: 1.20	0.60	0.00				
V[FT/SEC]: 72.65	51.37	0.00				

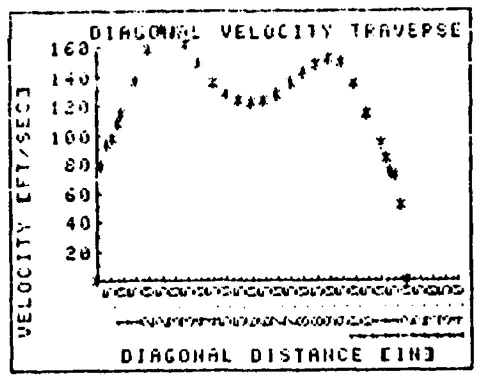
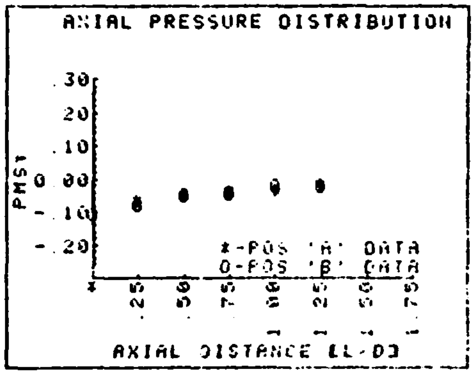


Table XII. (contd) VTD

MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA:				DIAGONAL (POSITION 'B') DATA:			
X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*	X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-2 650	45	-0.324	0 00	-0 870	45	-0.106
0.25	-0.530	45	-0.065	0 25	-0.610	45	-0.074
0.50	-0.300	0	-0.046	0.50	-0.410	0	-0.050
0.75	-0.290	0	-0.034	0.75	-0.340	0	-0.042
1.00	-0.230	0	-0.028	1 00	-0 160	0	-0.020
1.25	-0.120	0	-0.015	1.25	-0.130	0	-0.016



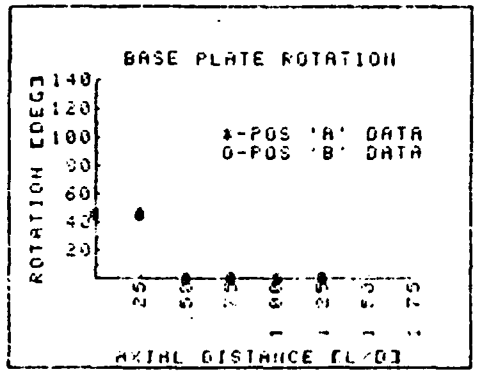


Table XII. (tontd) MSD

DATA TAKEN ON: 14 JAN 83
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.42

COMMENTS:
.25 X MASS FLOW RUN

MIXING STACK INFORMATION:		PRIMARY NOZZLE INFORMATION:		MISCELLANEOUS INFORMATION:	
LENGTH:	11.50 [IN]	TILT ANGLE:	0.0 [DEG]	ORIFICE DIAMETER:	6.902 [IN]
DIAMETER:	5.75 [IN]	ROTATION ANGLE:	0 [DEG]	ORIFICE BETA:	0.497
L/D RATIO:	2.00	AREA PER NOZZLE:	10.752 [IN2]	UPTAKE AREA:	25.970 [IN2]
S/D RATIO:	0.50	NUMBER OF NOZZLES:	1	ATM. PRESSURE:	29.80 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES		F		IN OF H2O		SQUARE INCHES	SQUARE INCHES
1	0.035	.4	47.4	116.8	47.6	1.10	0.56	0.00	0.000	*******
2	0.035	.4	47.8	119.4	47.8	1.50	0.17	0.00	12.566	*******
3	0.035	.4	48.0	120.0	48.0	1.60	0.08	0.00	25.133	*******
4	0.035	.4	48.2	120.8	48.0	1.60	0.03	0.00	50.265	*******
5	0.035	.4	48.6	121.4	48.2	1.60	0.01	0.00	100.531	*******
6	0.035	.4	48.8	122.4	48.4	1.60	0.01	0.00	150.796	*******
7	0.035	.4	48.8	123.6	48.4	1.60	0.00	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^ 44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.2424	0.8800	0.2754	0.0000	0.5092	0.0000	99.64	41.26	41.25	0.035
2	0.3536	0.0731	0.8764	0.0835	0.3337	0.5090	0.1800	99.95	54.21	41.38	0.035
3	0.4852	0.0344	0.8758	0.0393	0.4577	0.5089	0.2469	100.01	59.00	41.41	0.035
4	0.5943	0.0129	0.8746	0.0147	0.5603	0.5088	0.3024	100.12	63.00	41.45	0.035
5	0.6864	0.0043	0.8740	0.0049	0.6469	0.5086	0.3491	100.18	66.37	41.48	0.035
6	1.0296	0.0043	0.8729	0.0049	0.9698	0.5085	0.5236	100.33	78.88	41.54	0.035
7	******	0.0000	0.8711	0.0000	******	0.5085		100.54	******	41.62	0.035

Table XIII. 55 Percent Design Flow Rate

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.8800	0.0000	*******	0.509	*******	******
2	******	0.0000	0.8764	0.0000	*******	0.689	*******	******
3	******	0.0000	0.8758	0.0000	*******	0.756	*******	******
4	******	0.0000	0.8746	0.0000	*******	0.811	*******	******
5	******	0.0000	0.8740	0.0000	*******	0.858	*******	******
6	******	0.0000	0.8729	0.0000	*******	1.032	*******	******
7	******	0.0000	0.8711	0.0000	*******	******	*******	******

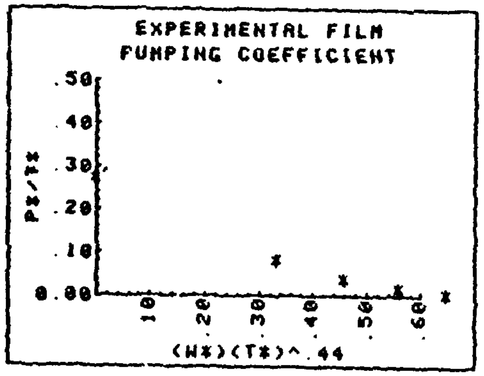


Table XIII. (contd) PCD

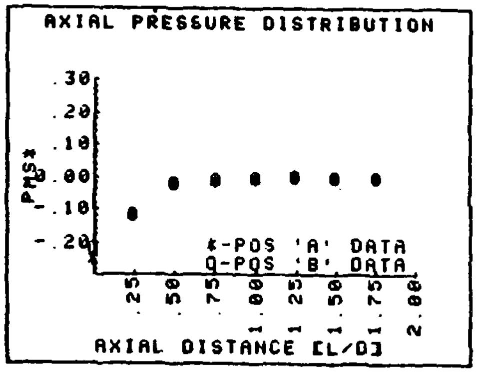
MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA:

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-0.590	0	-0.251
0.25	-0.270	0	-0.115
0.50	-0.050	0	-0.021
0.75	-0.030	0	-0.013
1.00	-0.020	0	-0.009
1.25	0.010	0	0.004
1.50	0.000	0	0.000
1.75	-0.010	0	-0.004

DIAGONAL (POSITION 'B') DATA:

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-0.510	0	-0.217
0.25	-0.270	0	-0.115
0.50	-0.050	0	-0.021
0.75	-0.020	0	-0.009
1.00	-0.010	0	-0.004
1.25	0.000	0	0.000
1.50	0.000	0	0.000
1.75	-0.010	0	-0.004



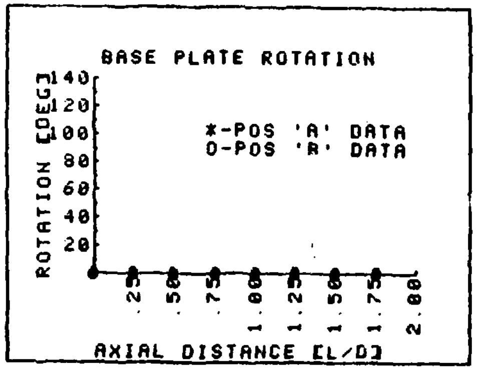
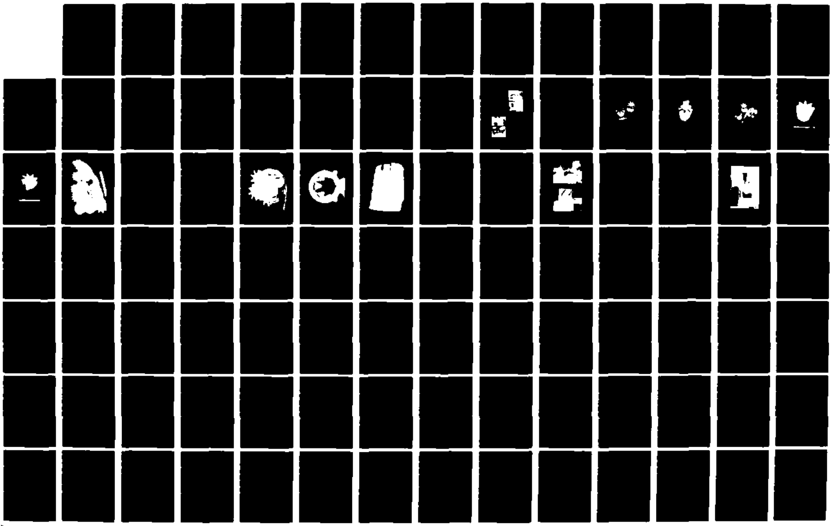
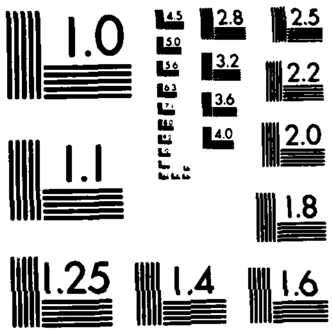


Table XIII. (contd) MSD

AD-A128 065 CHARACTERISTICS OF A FLUTE NOZZLE GAS EDUCTOR SYSTEM 2/3
(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA J W BOYKIN
MAR 83

UNCLASSIFIED F/G 21/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DATA TAKEN ON: 04 DEC 82
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.42

COMMENTS:
6" STACK FLUTED NOZZLE FULL RUN

MIXING STACK INFORMATION:
LENGTH: 11.50 [IN]
DIAMETER: 5.75 [IN]
L/D RATIO: 2.00
S/D RATIO: 0.50

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 1

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 25.970 [IN2]
ATM. PRESSURE: 30.05 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.055	1.3	62.6	130.2	70.4	3.70	2.18	0.00	0.000	*******
2	0.055	1.3	63.2	131.2	70.6	5.10	0.60	0.00	12.566	*******
3	0.055	1.3	63.2	131.2	70.8	5.40	0.26	0.00	25.133	*******
4	0.055	1.3	63.6	131.8	70.6	5.60	0.07	0.00	50.265	*******
5	0.055	1.3	62.8	132.2	70.8	5.60	0.02	0.00	100.531	*******
6	0.055	1.3	62.6	132.6	71.0	5.70	0.01	0.00	150.796	*******
7	0.055	1.3	62.6	133.0	71.0	5.70	0.00	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3031	0.8986	0.3373	0.0000	0.8978	0.0000	178.96	74.10	74.09	0.062
2	0.3702	0.0839	0.8974	0.0935	0.3530	0.8973	0.3322	178.47	98.41	73.89	0.062
3	0.4874	0.0364	0.8978	0.0406	0.4648	0.8973	0.4373	178.32	106.12	73.83	0.062
4	0.5060	0.0098	0.8965	0.0109	0.4823	0.8970	0.4539	178.35	107.35	73.84	0.062
5	0.5405	0.0028	0.8963	0.0031	0.5150	0.8976	0.4852	178.59	109.76	73.94	0.062
6	0.5730	0.0014	0.8960	0.0016	0.5460	0.8978	0.5145	178.74	112.00	74.00	0.062
7	******	0.0000	0.8954	0.0000	******	0.8978		178.85	******	74.05	0.062

Table XIV. 100 Percent Design Flow Rate

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.8986	0.0000	*******	0.898	*******	******
2	******	0.0000	0.8974	0.0000	*******	1.230	*******	******
3	******	0.0000	0.8970	0.0000	*******	1.335	*******	******
4	******	0.0000	0.8965	0.0000	*******	1.351	*******	******
5	******	0.0000	0.8963	0.0000	*******	1.383	*******	******
6	******	0.0000	0.8960	0.0000	*******	1.412	*******	******
7	******	0.0000	0.8954	0.0000	*******	******	*******	******

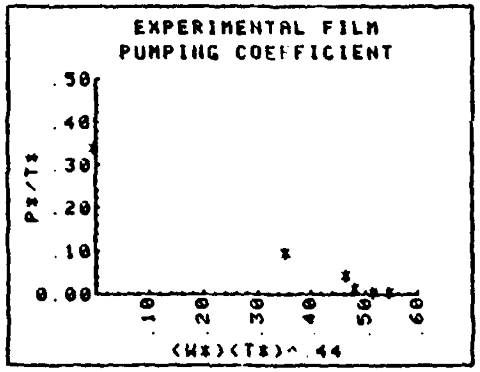
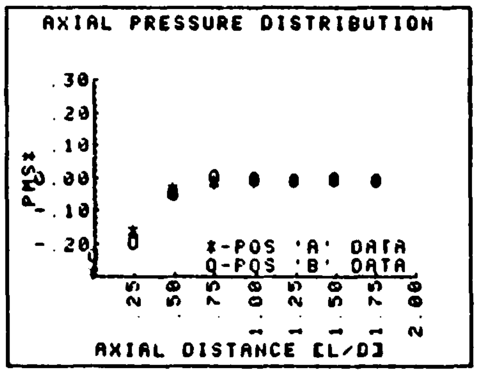


Table XIV. (contd) PCD

MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA: X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*	DIAGONAL (POSITION 'B') DATA: X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-2.060	0	-0.287	0.00	-1.700	0	-0.237
0.25	-1.140	0	-0.159	0.25	-1.420	0	-0.198
0.50	-0.250	0	-0.035	0.50	-0.340	0	-0.047
0.75	-0.100	0	-0.014	0.75	0.030	0	0.004
1.00	-0.060	0	-0.008	1.00	-0.030	0	-0.004
1.25	-0.070	0	-0.010	1.25	-0.060	0	-0.008
1.50	-0.060	0	-0.008	1.50	-0.030	0	-0.004
1.75	-0.050	0	-0.007	1.75	-0.050	0	-0.007



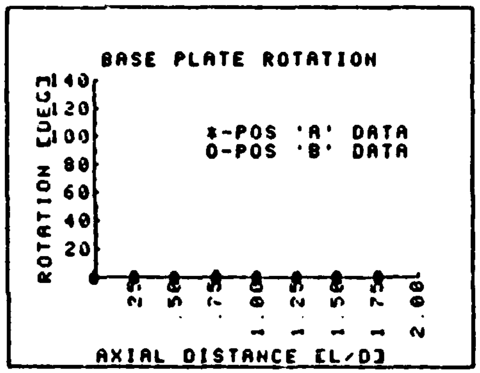


Table XIV. (contd) MSD

DATA TAKEN ON: 14 JAN 83
DATA TAKEN BY: J. W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.42

COMMENTS:
1.5 X MASS FLOW RUN

MIXING STACK INFORMATION:
LENGTH: 11.50 [IN]
DIAMETER: 5.75 [IN]
L/D RATIO: 2.00
S/D RATIO: 0.50

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 1

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 25.970 [IN2]
ATM. PRESSURE: 29.80 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	RTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.070	1.9	45.8	100.8	44.0	5.20	3.26	0.00	0.000	*******
2	0.065	1.9	45.8	105.2	44.8	7.20	0.88	0.00	12.566	*******
3	0.065	1.9	46.2	106.2	44.8	7.60	0.37	0.00	25.133	*******
4	0.065	1.9	46.0	107.0	45.0	7.80	0.12	0.00	50.265	*******
5	0.065	1.9	46.4	108.0	45.2	7.90	0.04	0.00	100.531	*******
6	0.065	1.9	46.4	109.2	45.2	7.90	0.02	0.00	150.796	*******
7	0.065	1.9	46.4	110.0	45.4	7.90	0.01	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.3006	0.8987	0.3345	0.0000	1.1232	0.0000	215.10	89.07	89.06	0.077
2	0.3657	0.0810	0.8931	0.0907	0.3480	1.1232	0.4108	215.52	118.32	89.23	0.077
3	0.4745	0.0340	0.8915	0.0382	0.4511	1.1228	0.5327	215.54	126.96	89.24	0.077
4	0.5402	0.0110	0.8906	0.0124	0.5133	1.1230	0.6066	215.76	132.30	89.33	0.077
5	0.6239	0.0037	0.8894	0.0041	0.5925	1.1225	0.7004	216.01	139.06	89.43	0.077
6	0.6617	0.0018	0.8875	0.0021	0.6279	1.1225	0.7428	216.45	142.26	89.62	0.077
7	******	0.0009	0.8866	0.0010	******	1.1225		216.75	******	89.74	0.077

Table XV. 125 Percent Design Flow Rate

TERTIARY BOX

N RUN	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM LBM/SEC	WT LBM/SEC	UE FT/SEC
1	******	0.0000	0.8987	0.0000	*******	1.123	*******	******
2	******	0.0000	0.8931	0.0000	*******	1.534	*******	******
3	******	0.0000	0.8915	0.0000	*******	1.655	*******	******
4	******	0.0000	0.6906	0.0000	*******	1.730	*******	******
5	******	0.0000	0.8894	0.0000	*******	1.823	*******	******
6	******	0.0000	0.8875	0.0000	*******	1.865	*******	******
7	******	0.0000	0.8866	0.0000	*******	******	*******	******

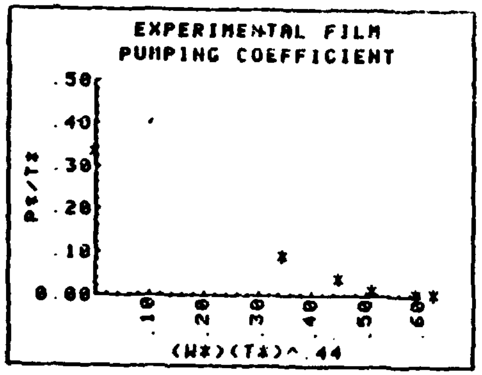
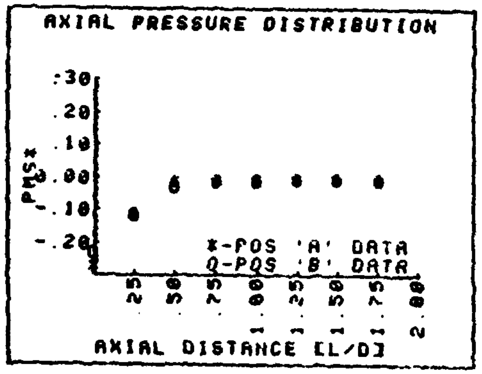


Table XV. (contd) PCD

MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA: X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*	DIAGONAL (POSITION 'B') DATA: X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-2.960	0	-0.270	0.00	-2.530	0	-0.230
0.25	-1.280	0	-0.117	0.25	-1.280	0	-0.117
0.50	-0.150	0	-0.014	0.50	-0.350	0	-0.032
0.75	-0.160	0	-0.015	0.75	-0.160	0	-0.015
1.00	-0.110	0	-0.010	1.00	-0.120	0	-0.011
1.25	-0.100	0	-0.009	1.25	-0.070	0	-0.006
1.50	-0.070	0	-0.006	1.50	-0.090	0	-0.008
1.75	-0.080	0	-0.007	1.75	-0.080	0	-0.007



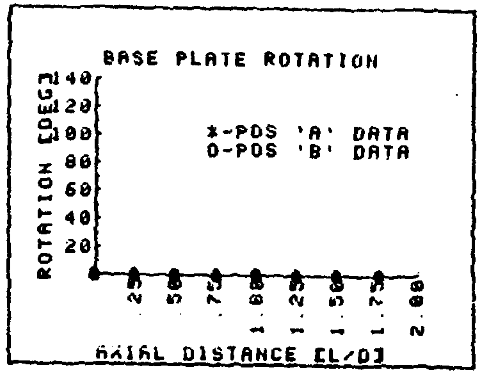


Table XV. (contd) MSD

DATA TAKEN ON: 14 JAN 83
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.42

COMMENTS:
L/D=2.0 FULL RUN

MIXING STACK INFORMATION:
LENGTH: 11.50 [IN]
DIAMETER: 5.75 [IN]
L/D RATIO: 2.00
S/D RATIO: 0.50

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: 0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 1

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 25.970 [IN2]
ATM. PRESSURE: 29.80 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES	F		IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.055	1.3	50.2	134.6	50.6	3.50	2.15	0.00	0.000	*******
2	0.055	1.3	50.4	133.2	51.0	5.00	0.58	0.00	12.566	*******
3	0.055	1.3	50.6	132.4	51.2	5.40	0.25	0.00	25.133	*******
4	0.055	1.3	50.0	131.0	51.4	5.50	0.08	0.00	50.265	*******
5	0.055	1.3	50.0	130.4	51.6	5.60	0.02	0.00	100.531	*******
6	0.055	1.3	50.4	130.0	51.6	5.60	0.01	0.00	150.796	*******
7	0.055	1.3	51.0	129.2	51.8	5.60	0.00	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.2746	0.8587	0.3198	0.0000	0.9084	0.0000	183.95	76.17	76.16	0.064
2	0.3649	0.0751	0.8614	0.0872	0.3417	0.9082	0.3315	182.77	99.43	75.67	0.063
3	0.4792	0.0325	0.8629	0.0377	0.4491	0.9081	0.4351	182.34	106.70	75.49	0.063
4	0.5417	0.0105	0.8652	0.0121	0.5083	0.9086	0.4922	181.94	110.64	75.33	0.063
5	0.5416	0.0026	0.8665	0.0030	0.5085	0.9086	0.4921	181.73	110.56	75.24	0.063
6	0.5747	0.0013	0.8670	0.0015	0.5397	0.9082	0.5220	181.53	112.62	75.16	0.063
7	******	0.0000	0.8686	0.0000	******	0.9077		181.17	******	75.01	0.063

Table XVI. Single Fluted Nozzle: L/D = 2.0

TERTIARY BOX

N RUN	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM LBM/SEC	WT LBM/SEC	UE FT/SEC
1	******	0.0000	0.8587	0.0000	*******	0.908	*******	******
2	******	0.0000	0.8614	0.0000	*******	1.240	*******	******
3	******	0.0000	0.8629	0.0000	*******	1.343	*******	******
4	******	0.0000	0.8652	0.0000	*******	1.401	*******	******
5	******	0.0000	0.8665	0.0000	*******	1.401	*******	******
6	******	0.0000	0.8670	0.0000	*******	1.430	*******	******
7	******	0.0000	0.8686	0.0000	*******	******	*******	******

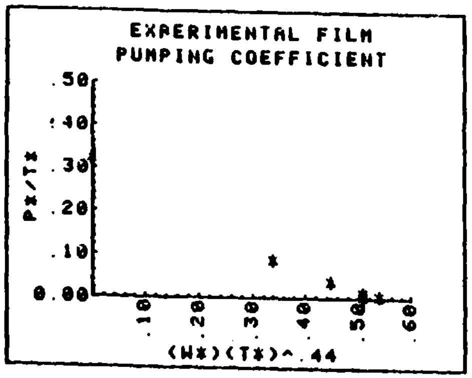
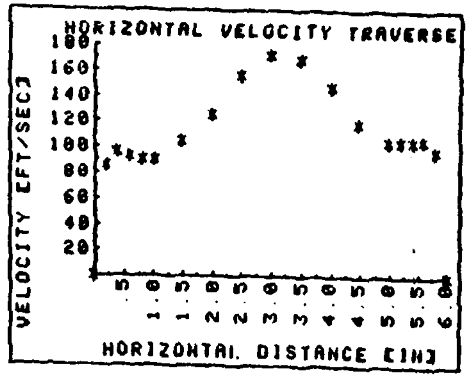


Table XVI. (contd) PCD

HORIZONTAL VELOCITY TRAVERSE AT BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	1.70	2.10	2.00	1.90	1.90	2.50
V[FT/SEC]:	0.00	85.82	95.39	93.09	90.73	90.73	104.07
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	3.60	5.60	6.80	6.60	5.00	3.30	2.50
V[FT/SEC]:	124.89	155.76	171.64	169.10	147.18	119.57	104.07
POSIT[IN]:	5.20	5.40	5.60	5.80	6.00		
P[IN H2O]:	2.50	2.50	2.60	2.20	0.00		
V[FT/SEC]:	104.07	104.07	106.13	97.63	0.00		



DIAGONAL VELOCITY TRAVERSE FOR BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	1.30	2.00	2.00	1.90	1.90	2.40
V[FT/SEC]:	0.00	75.05	93.09	93.09	90.73	90.73	101.97
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	3.70	5.60	6.80	6.50	4.70	2.90	2.30
V[FT/SEC]:	126.61	158.52	171.64	167.81	142.70	112.09	99.82
POSIT[IN]:	5.20	5.40	5.60	5.80	6.00		
P[IN H2O]:	2.30	2.40	2.60	2.20	0.00		
V[FT/SEC]:	99.82	101.97	106.13	97.63	0.00		

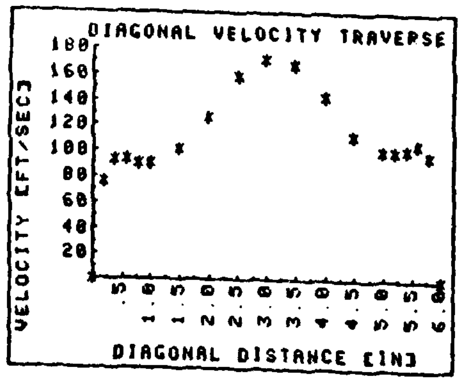


Table XVI. (contd) VTD

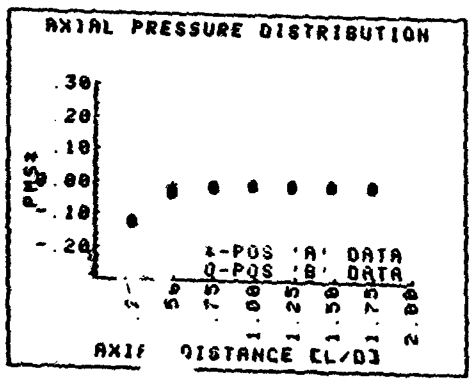
MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA:

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-2.070	0	-0.273
0.25	-0.910	0	-0.120
0.50	-0.150	0	-0.020
0.75	-0.110	0	-0.015
1.00	-0.070	0	-0.009
1.25	-0.050	0	-0.007
1.50	-0.040	0	-0.005
1.75	-0.040	0	-0.005

DIAGONAL (POSITION 'B') DATA:

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-1.760	0	-0.232
0.25	-0.910	0	-0.120
0.50	-0.230	0	-0.030
0.75	-0.100	0	-0.013
1.00	-0.070	0	-0.009
1.25	-0.040	0	-0.005
1.50	-0.040	0	-0.005
1.75	-0.063	0	-0.008



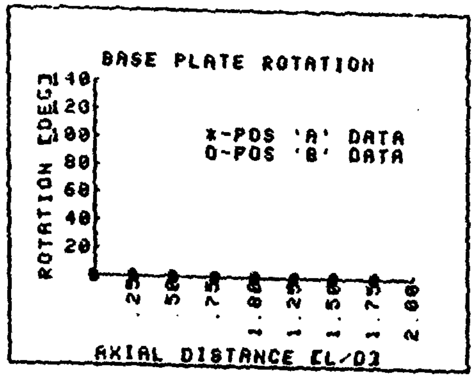


Table XVI. (contd) MSD

DATA TAKEN ON: 16 JAN 83
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.42

COMMENTS:
L/D=1.75 FULL RUN

MIXING STACK INFORMATION:
LENGTH: 10.10 [IN]
DIAMETER: 5.75 [IN]
L/D RATIO: 1.75
S/D RATIO: 0.50

PRIMARY NOZZLE INFORMATION:
TILT ANGLE: 0.0 [DEG]
ROTATION ANGLE: .0 [DEG]
AREA PER NOZZLE: 10.752 [IN2]
NUMBER OF NOZZLES: 1

MISCELLANEOUS INFORMATION:
ORIFICE DIAMETER: 6.902 [IN]
ORIFICE BETA: 0.497
UPTAKE AREA: 25.970 [IN2]
ATM. PRESSURE: 29.82 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.055	1.3	56.0	95.0	59.0	3.40	1.95	0.00	0.000	*******
2	0.055	1.3	55.6	102.0	59.8	4.60	0.55	0.00	12.566	*******
3	0.055	1.3	55.6	105.0	59.8	4.90	0.23	0.00	25.133	*******
4	0.055	1.3	55.6	109.6	59.8	5.00	0.07	0.00	50.265	*******
5	0.055	1.3	55.6	111.6	59.8	5.00	0.02	0.00	100.531	*******
6	0.055	1.3	55.4	113.4	59.8	5.10	0.01	0.00	150.796	*******
7	0.055	1.3	55.4	115.6	59.8	5.10	0.00	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.2994	0.9365	0.3196	0.0000	0.8965	0.0000	169.25	70.09	70.07	0.061
2	0.3569	0.0828	0.9249	0.0896	0.3449	0.8969	0.3201	170.86	94.07	70.74	0.061
3	0.4580	0.0337	0.9187	0.0367	0.4413	0.9040	0.4140	173.24	101.90	71.72	0.062
4	0.5094	0.0103	0.9125	0.0113	0.4893	0.8969	0.4560	172.96	104.90	71.61	0.061
5	0.5445	0.0029	0.9093	0.0032	0.5222	0.8969	0.4804	173.55	107.44	71.85	0.061
6	0.5775	0.0015	0.9065	0.0016	0.5530	0.8970	0.5180	174.13	109.84	72.09	0.061
7	******	0.0000	0.9030	0.0000	******	0.8970	-	174.79	******	72.37	0.062

Table XVII. Single Fluted Nozzle: L/D = 1.75

TERTIARY BOX

N RUN	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM LBM/SEC	WT LBM/SEC	VE FT/SEC
1	******	0.0000	0.9365	0.0000	*******	0.897	*******	******
2	******	0.0000	0.9249	0.0000	*******	1.217	*******	******
3	******	0.0000	0.9187	0.0000	*******	1.318	*******	******
4	******	0.0000	0.9125	0.0000	*******	1.354	*******	******
5	******	0.0000	0.9093	0.0000	*******	1.385	*******	******
6	******	0.0000	0.9065	0.0000	*******	1.415	*******	******
7	******	0.0000	0.9030	0.0000	*******	******	*******	******

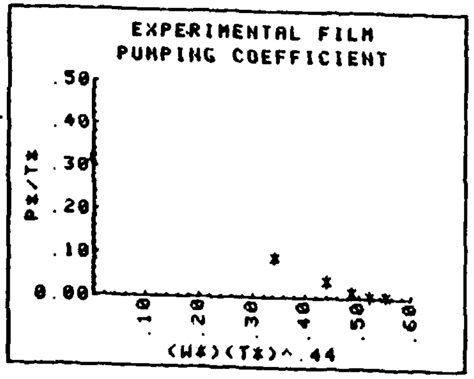
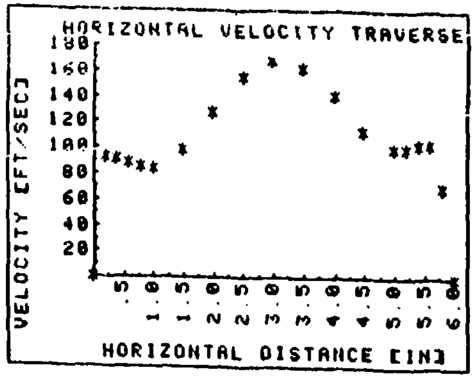


Table XVII. (contd) PCD

HORIZONTAL VELOCITY TRAVERSE AT BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	2.00	1.90	1.80	1.70	1.60	2.20
V[FT/SEC]:	0.00	93.79	91.41	83.37	86.46	83.60	98.36
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	3.70	5.50	6.50	6.60	4.50	2.90	2.30
V[FT/SEC]:	127.55	155.52	169.06	162.43	140.67	112.93	100.57
POSIT[IN]:	5.20	5.40	5.60	5.80	6.00		
P[IN H2O]:	2.30	2.40	2.40	1.10	0.00		
V[FT/SEC]:	100.57	102.73	102.73	69.55	0.00		



DIAGONAL VELOCITY TRAVERSE FOR BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	1.80	2.00	1.90	1.80	1.80	2.20
V[FT/SEC]:	0.00	88.97	93.78	91.41	88.97	88.97	98.36
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	3.50	5.70	6.60	6.40	4.70	2.70	2.10
V[FT/SEC]:	124.06	158.32	170.36	167.76	143.76	108.96	96.10
POSIT[IN]:	5.20	5.40	5.60	5.80	6.00		
P[IN H2O]:	2.10	2.30	2.50	1.80	0.00		
V[FT/SEC]:	96.10	100.57	104.85	88.97	0.00		

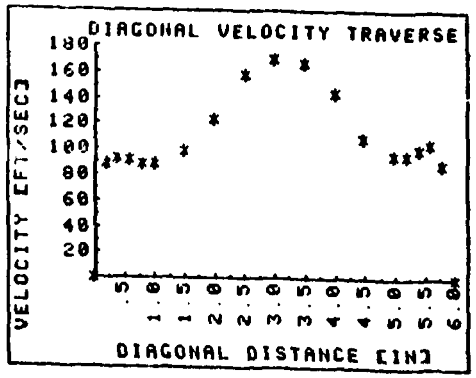


Table XVII. (contd) VTD

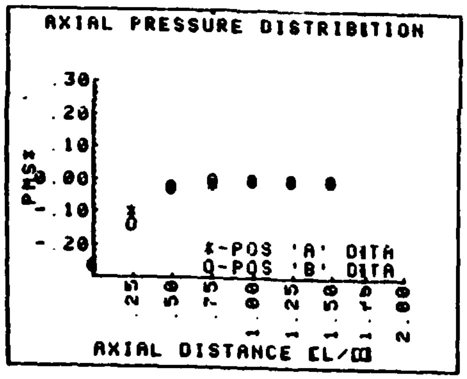
MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA:

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-1.850	0	-0.266
0.25	-0.700	0	-0.101
0.50	-0.180	0	-0.026
0.75	-0.080	0	-0.012
1.00	-0.020	0	-0.003
1.25	-0.010	0	-0.001
1.50	0.000	0	0.000

DIAGONAL (POSITION 'B') DATA:

X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-1.830	0	-0.263
0.25	-0.980	0	-0.141
0.50	-0.160	0	-0.023
0.75	-0.010	0	-0.001
1.00	-0.020	0	-0.003
1.25	0.000	0	0.000
1.50	0.000	0	0.000



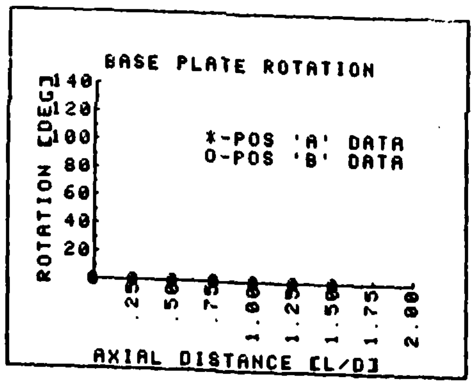


Table XVII. (contd) MSD

DATA TAKEN ON: 18 JAN 83
DATA TAKEN BY: J.W. BOYKIN

NOZZLE AM/AP AREA RATIO: 2.42

COMMENTS:
L/D=1.5 FULL RUN

MIXING STACK INFORMATION:		PRIMARY NOZZLE INFORMATION:		MISCELLANEOUS INFORMATION:	
LENGTH:	8.62 [IN]	TILT ANGLE:	0.0 [DEG]	ORIFICE DIAMETER:	6.902 [IN]
DIAMETER:	5.75 [IN]	ROTATION ANGLE:	0 [DEG]	ORIFICE BETA:	0.497
L/D RATIO:	1.50	AREA PER NOZZLE:	10.752 [IN2]	UPTAKE AREA:	25.970 [IN2]
S/D RATIO:	0.50	NUMBER OF NOZZLES:	1	ATM. PRESSURE:	29.60 [INHG]

N	POR	DPOR	TOR	TUPT	TAMB	PUPT	PSEC	PTER	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.055	1.3	55.8	128.0	59.2	3.50	2.69	0.00	0.000	*******
2	0.055	1.3	56.0	128.4	59.4	4.80	0.58	0.00	12.566	*******
3	0.055	1.3	56.4	129.0	59.4	5.10	0.23	9.00	25.133	*******
4	0.055	1.3	56.4	129.2	59.4	5.30	0.07	0.00	50.265	*******
5	0.055	1.3	56.2	129.6	59.6	5.30	0.02	0.00	100.531	*******
6	0.055	1.3	56.2	129.4	59.6	5.30	0.01	0.00	150.796	*******
7	0.055	1.3	56.4	130.2	59.6	5.30	0.00	0.00	*******	*******

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*T^.44	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.2829	0.8629	0.3204	0.0000	0.8981	0.0000	180.55	74.76	74.75	0.063
2	0.3654	0.0791	0.8827	0.0896	0.3459	0.8980	0.3281	179.96	98.51	74.51	0.063
3	0.4604	0.0314	0.8818	0.0356	0.4356	0.8976	0.4132	179.92	104.72	74.49	0.063
4	0.5079	0.0095	0.8815	0.0108	0.4805	0.8976	0.4559	179.91	107.84	74.49	0.063
5	0.5428	0.0027	0.8812	0.0031	0.5134	0.8978	0.4873	180.05	110.21	74.54	0.063
6	0.5757	0.0014	0.8815	0.0015	0.5447	0.8978	0.5169	179.98	112.34	74.51	0.063
7	******	0.0000	0.8803	0.0000	******	0.8976		180.19	******	74.60	0.063

Table XVIII. Single Fluted Nozzle: L/D = 1.50

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT^.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	******	0.0000	0.8829	0.0000	*******	0.898	*******	******
2	******	0.0000	0.8827	0.0000	*******	1.226	*******	******
3	******	0.0000	0.8818	0.0000	*******	1.311	*******	******
4	******	0.0000	0.8815	0.0000	*******	1.354	*******	******
5	******	0.0000	0.8812	0.0000	*******	1.385	*******	******
6	******	0.0000	0.8815	0.0000	*******	1.415	*******	******
7	******	0.0000	0.8803	0.0000	*******	******	*******	******

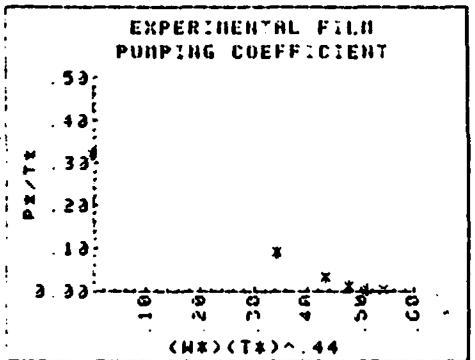
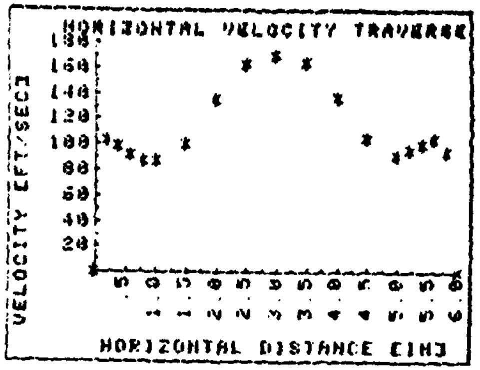


Table XVIII. (contd) PCD

HORIZONTAL VELOCITY TRAVERSE AT BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	2.40	2.20	1.90	1.70	1.70	2.30
V[FT/SEC]:	0.00	102.95	98.57	91.60	86.65	86.65	100.79
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	4.10	6.00	6.50	6.10	4.20	2.50	1.90
V[FT/SEC]:	134.56	162.78	169.43	164.13	136.19	105.08	91.60
POSIT[IN]:	5.20	5.40	5.60	5.80	6.00		
P[IN H2O]:	2.10	2.30	2.50	2.00	0.00		
V[FT/SEC]:	96.30	100.79	105.08	93.90	0.00		



DIAGONAL VELOCITY TRAVERSE FOR BASE ROTATION OF 00 DEGREES

POSIT[IN]:	0.00	0.20	0.40	0.60	0.80	1.00	1.50
P[IN H2O]:	0.00	2.00	2.10	1.90	1.80	1.70	2.30
V[FT/SEC]:	0.00	93.98	96.30	91.60	89.16	86.65	100.79
POSIT[IN]:	2.00	2.50	3.00	3.50	4.00	4.50	5.00
P[IN H2O]:	4.00	6.10	6.50	6.10	3.90	2.10	1.80
V[FT/SEC]:	132.91	164.13	169.43	164.13	131.24	96.30	89.16
POSIT[IN]:	5.20	5.40	5.60	5.80	6.00		
P[IN H2O]:	1.90	2.20	2.50	2.20	0.00		
V[FT/SEC]:	91.60	98.57	105.08	98.57	0.00		

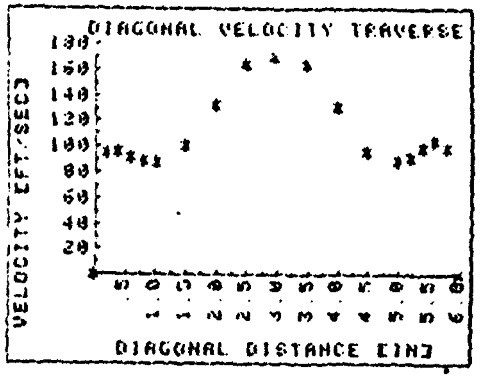
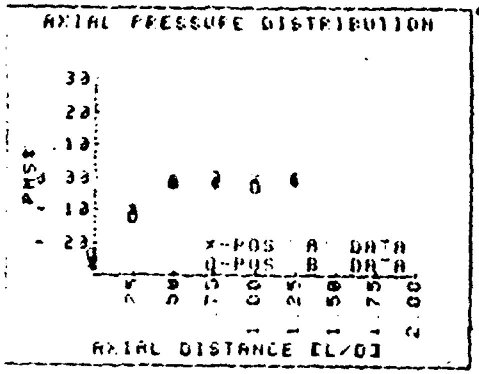


Table XVIII. (contd) VTD

MIXING STACK DATA FOR RUN 7

TOP (POSITION 'A') DATA				DIAGONAL (POSITION 'B') DATA			
X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*	X/D	PRESSURE [IN H2O]	ROTATION [DEG]	PMS*
0.00	-1.950	0	-0.265	0.00	-1.750	0	-0.230
0.25	-0.740	0	-0.101	0.25	-0.880	0	-0.120
0.50	-0.130	0	-0.018	0.50	-0.100	0	-0.014
0.75	-0.130	0	-0.018	0.75	0.000	0	0.000
1.00	-0.020	0	-0.003	1.00	-0.210	0	-0.029
1.25	-0.050	0	-0.007	1.25	-0.020	0	-0.003



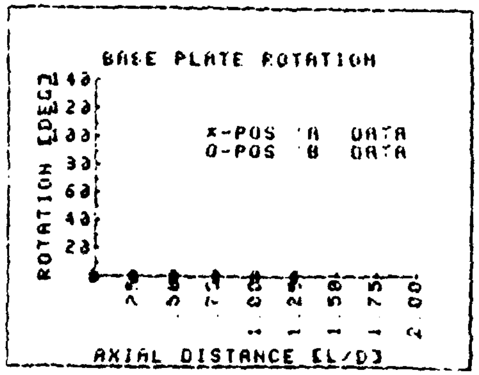


Table XVIII. (contd) MSD

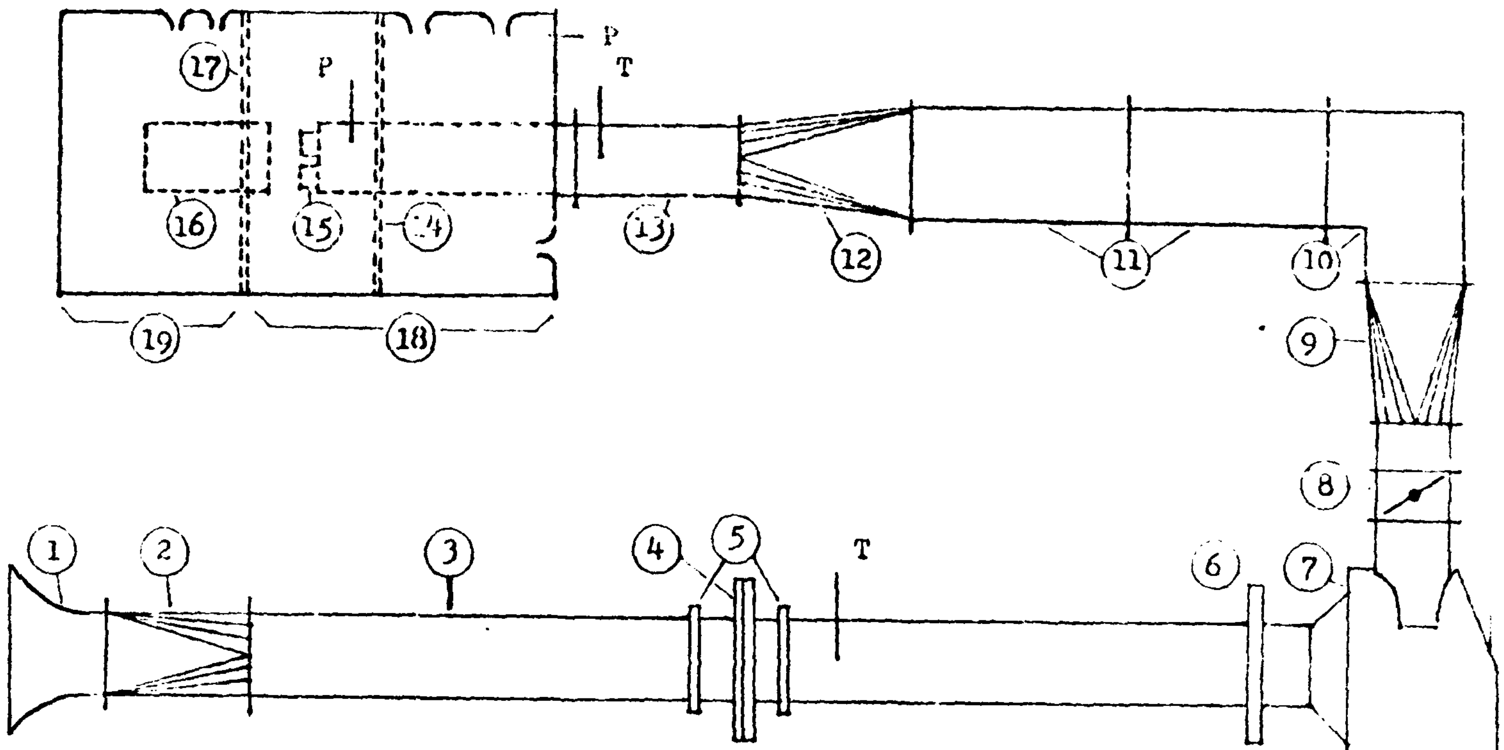


Figure 1. Eductor Model Testing Facility

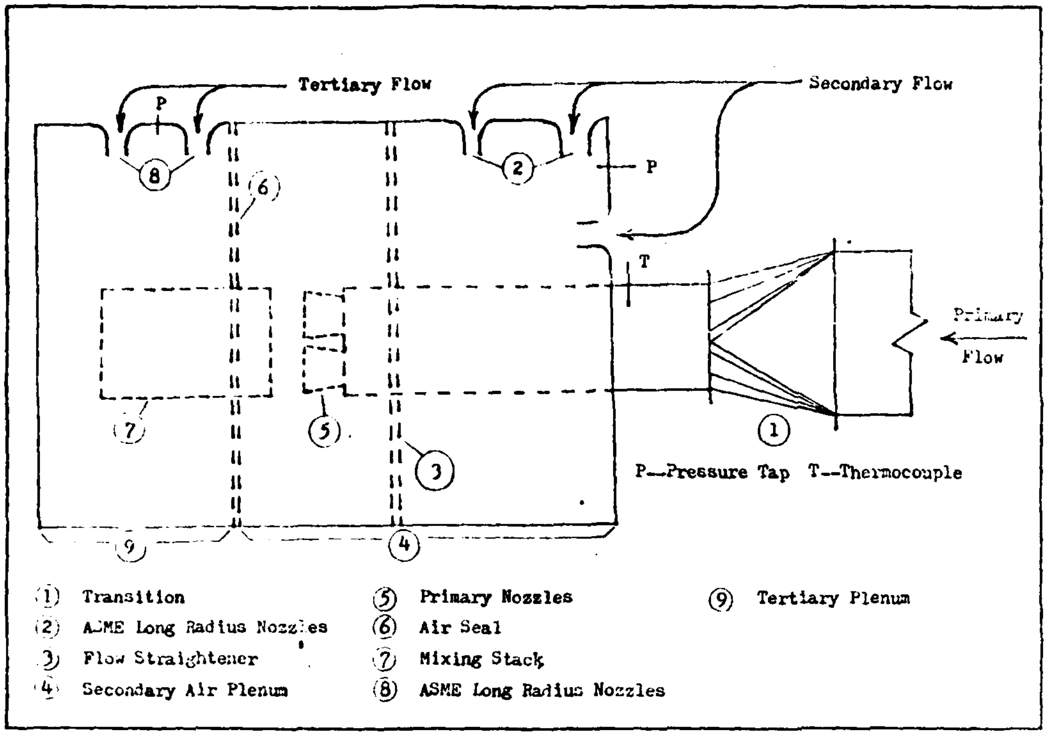


Figure 2. Test Facility with Secondary and Tertiary Plenums

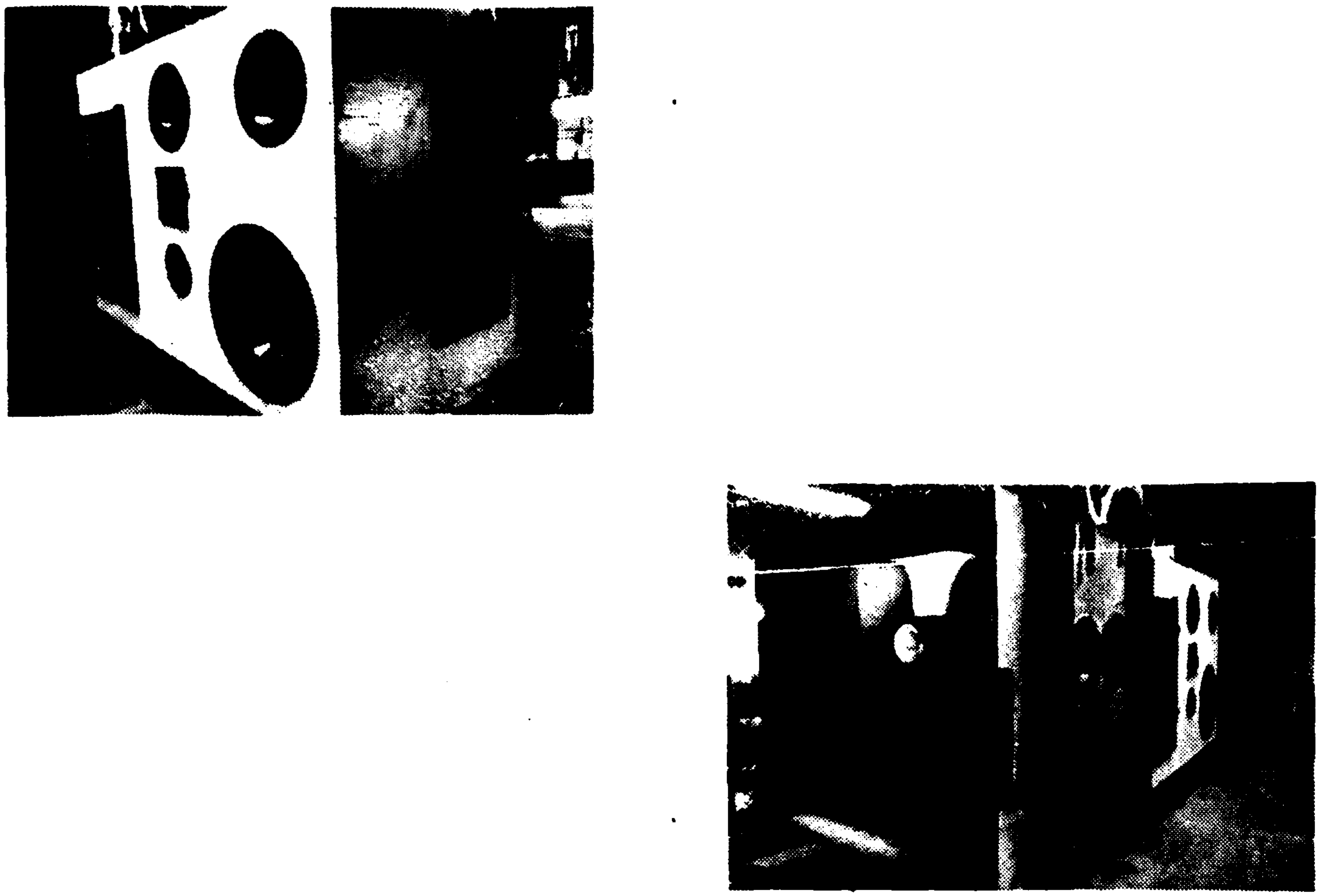


Figure 3. Exterior of Secondary and Tertiary Plenums

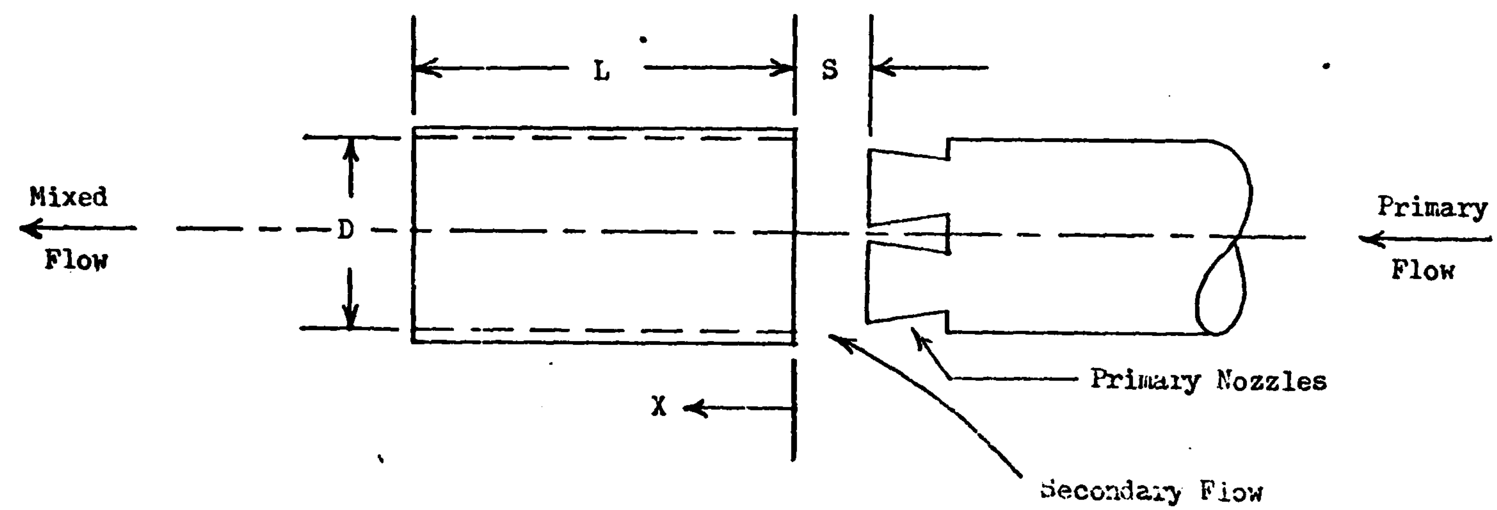


Figure 4. Schematic of Mixing Stack and Primary Nozzles

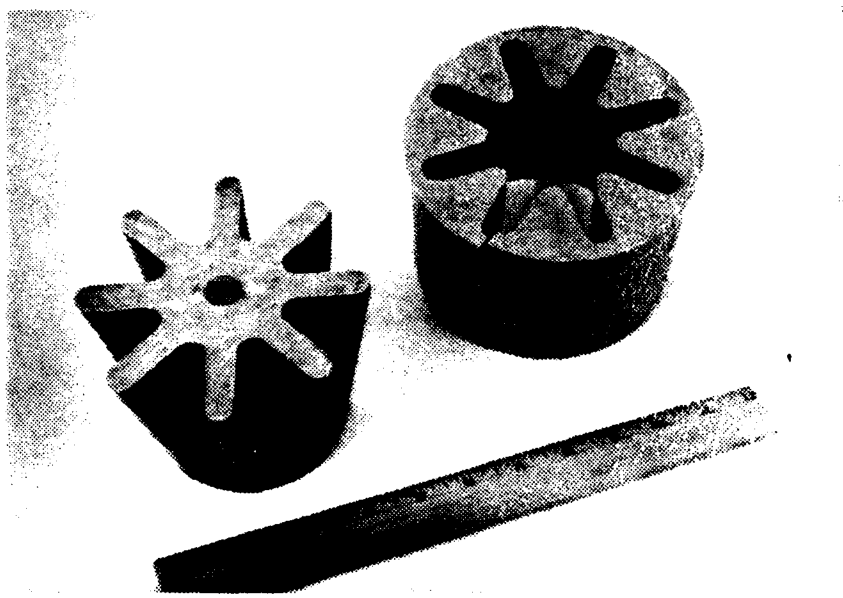


Figure 5. Wax Model and Female Rubber Mold

Figure 6. Plaster Mold Built Up Using Wax

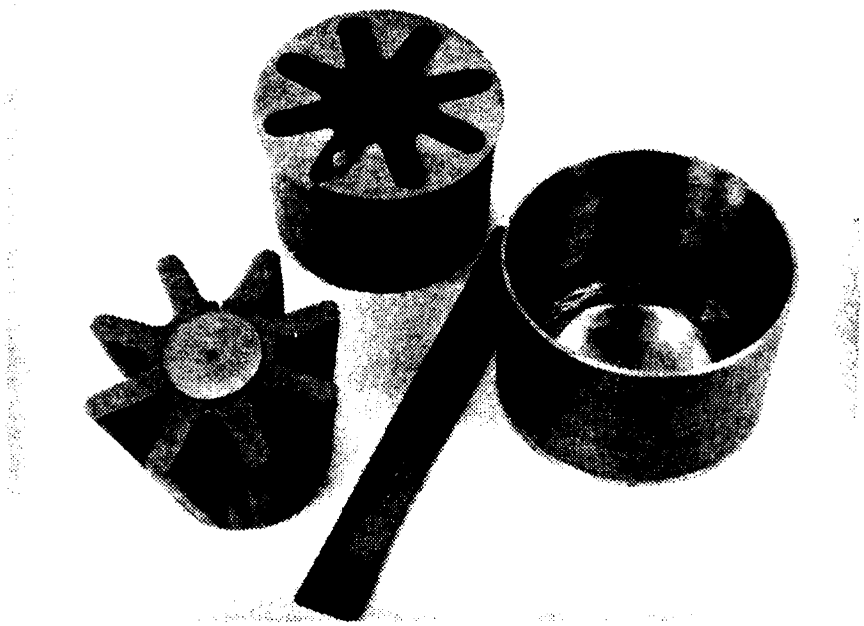


Figure 7. Metal Sleeve with Male and Female Rubber Molds

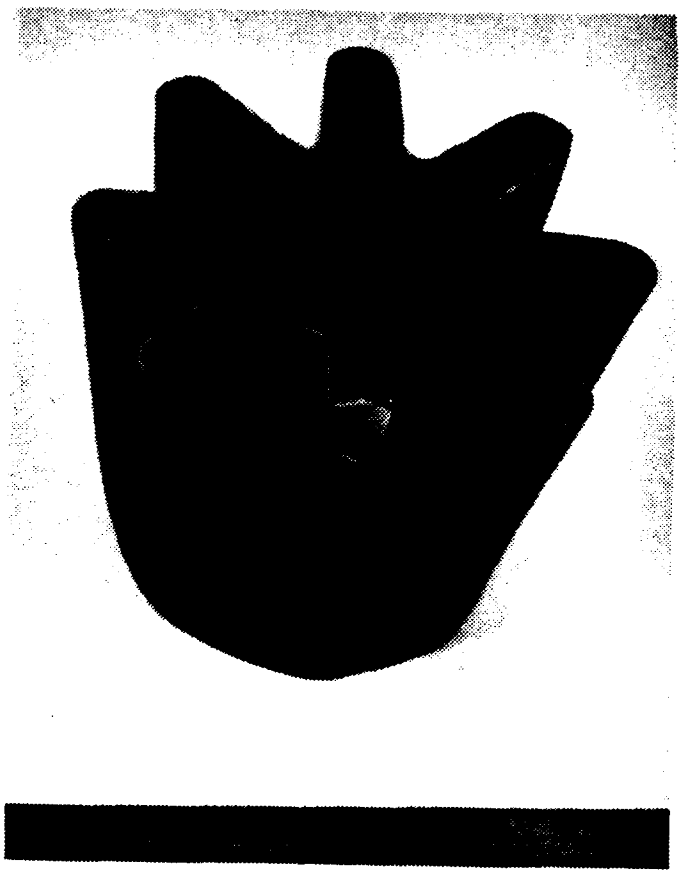


Figure 8. Fluted Section of Primary Nozzle

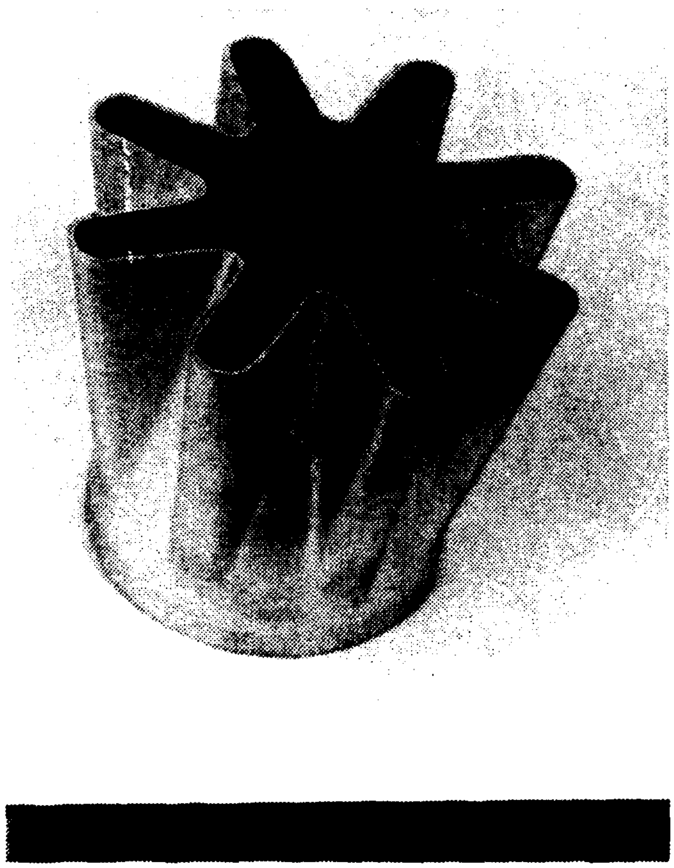
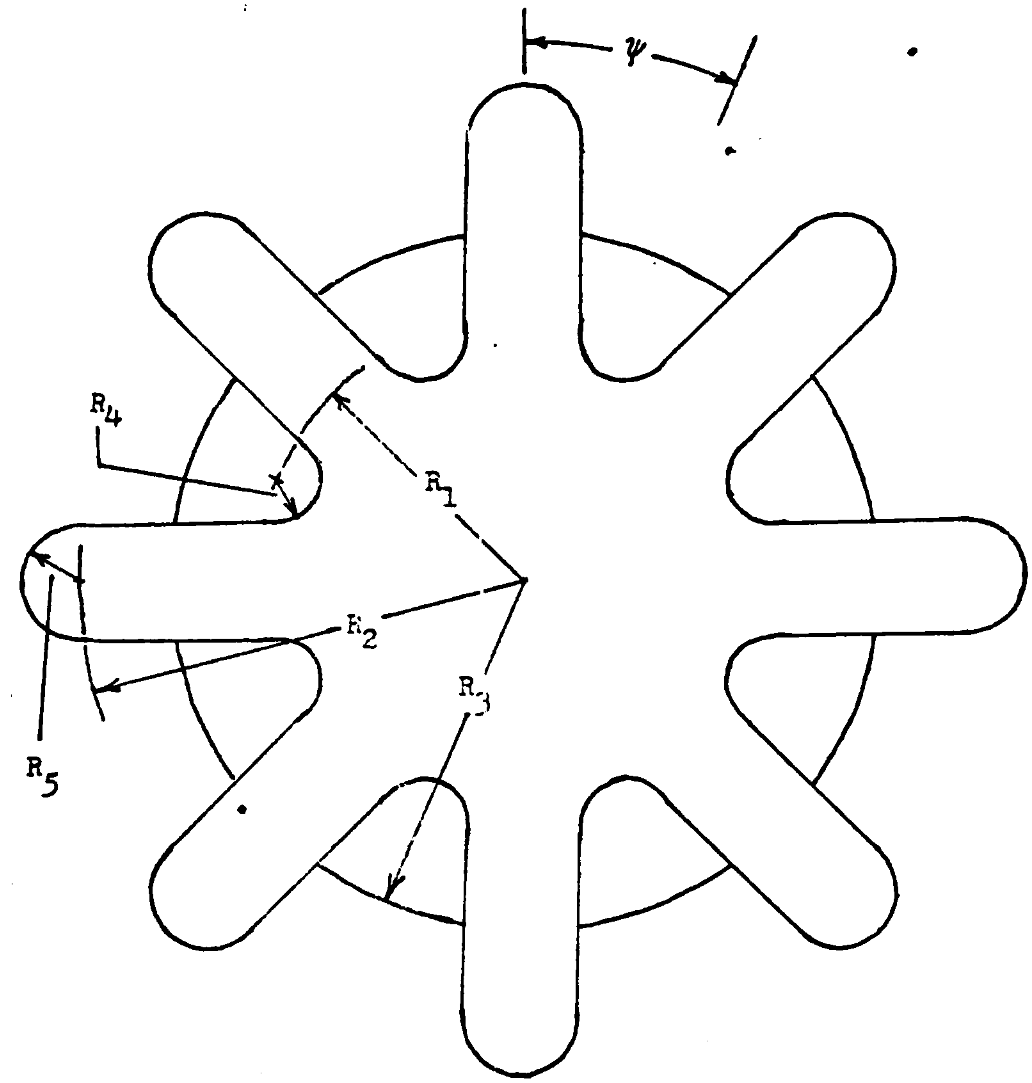


Figure 9. Finished Fluted Primary Nozzle

Figure 10. Nozzle Molding Process



RADII (INCHES)

R_1 = 1.3875	R_4 = 0.2535
R_2 = 2.3025	R_5 = 0.2775
R_3 = 1.8500	ψ = 22.5°

Figure 11. Dimensions of Primary Nozzle (End View)

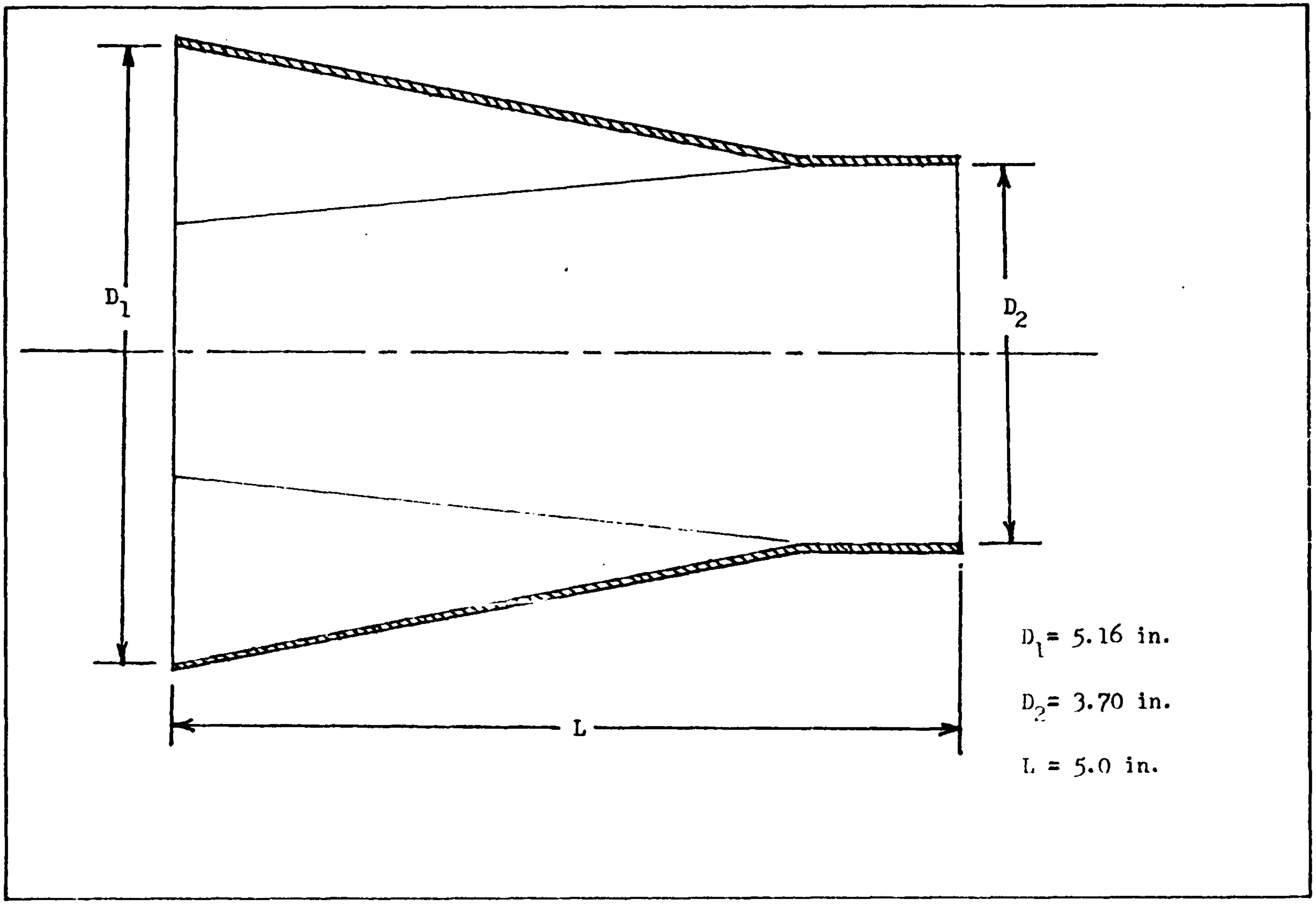


Figure 12. Dimensions of Primary Nozzle (Section View)

Figure 13. Four Nozzle Base Plate with Nozzles Installed

Figure 14. Single Nozzle Base Plate with Nozzle Installed

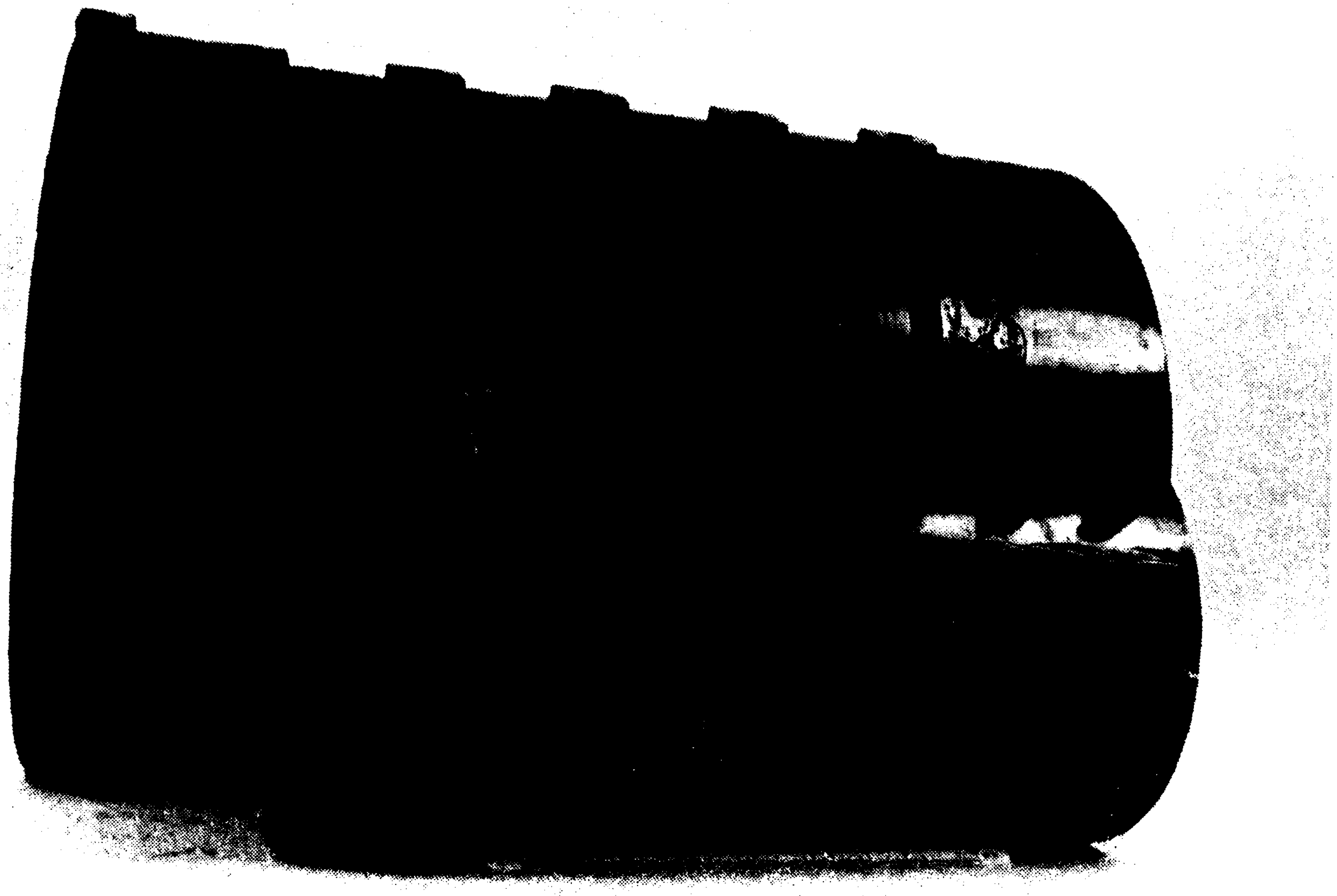


Figure 15. 12 Inch and 6 Inch Mixing Stacks

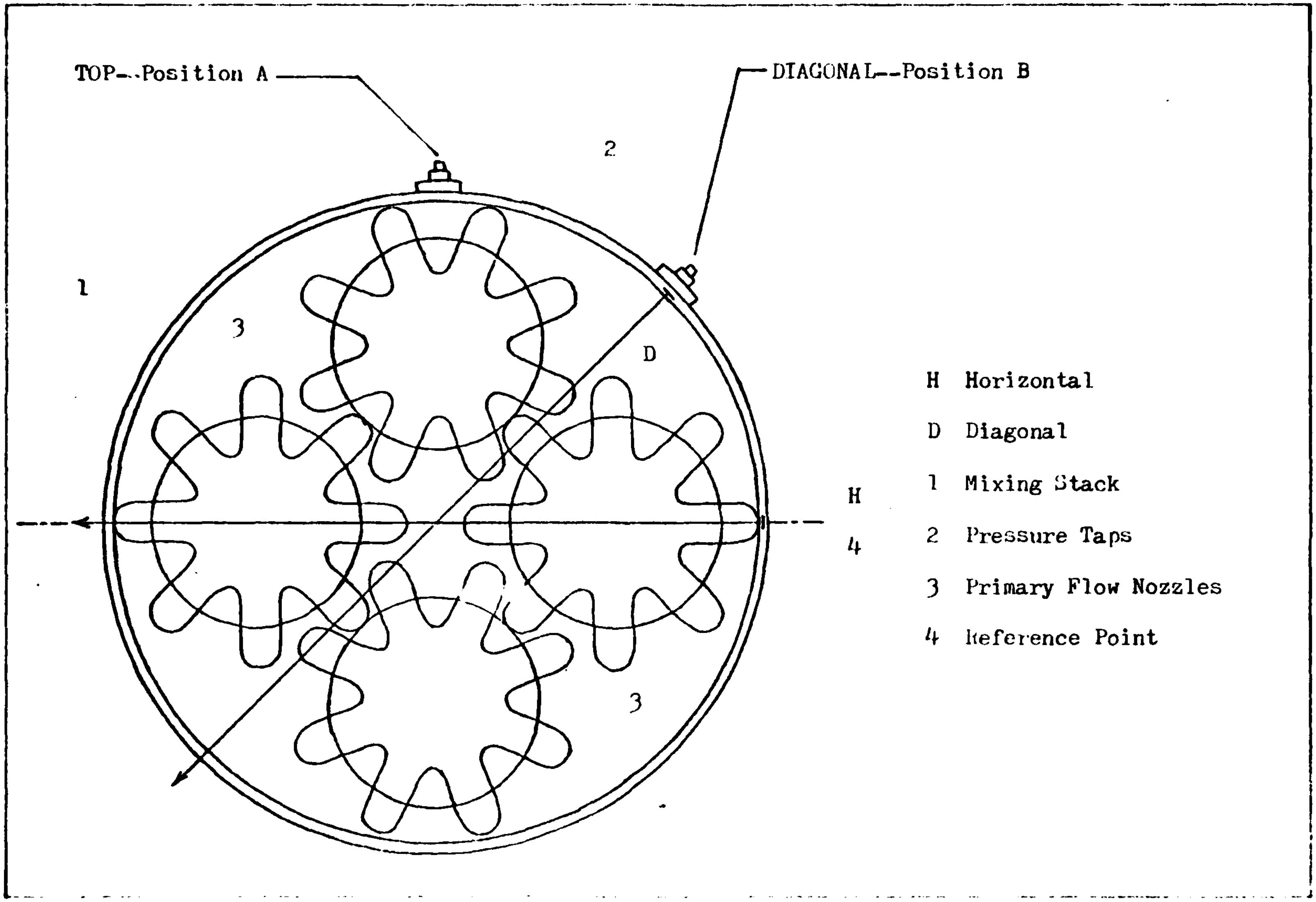


Figure 16. Mixing Stack Exit with Velocity Profile Directions and Pressure Tap Locations (Four Nozzle)

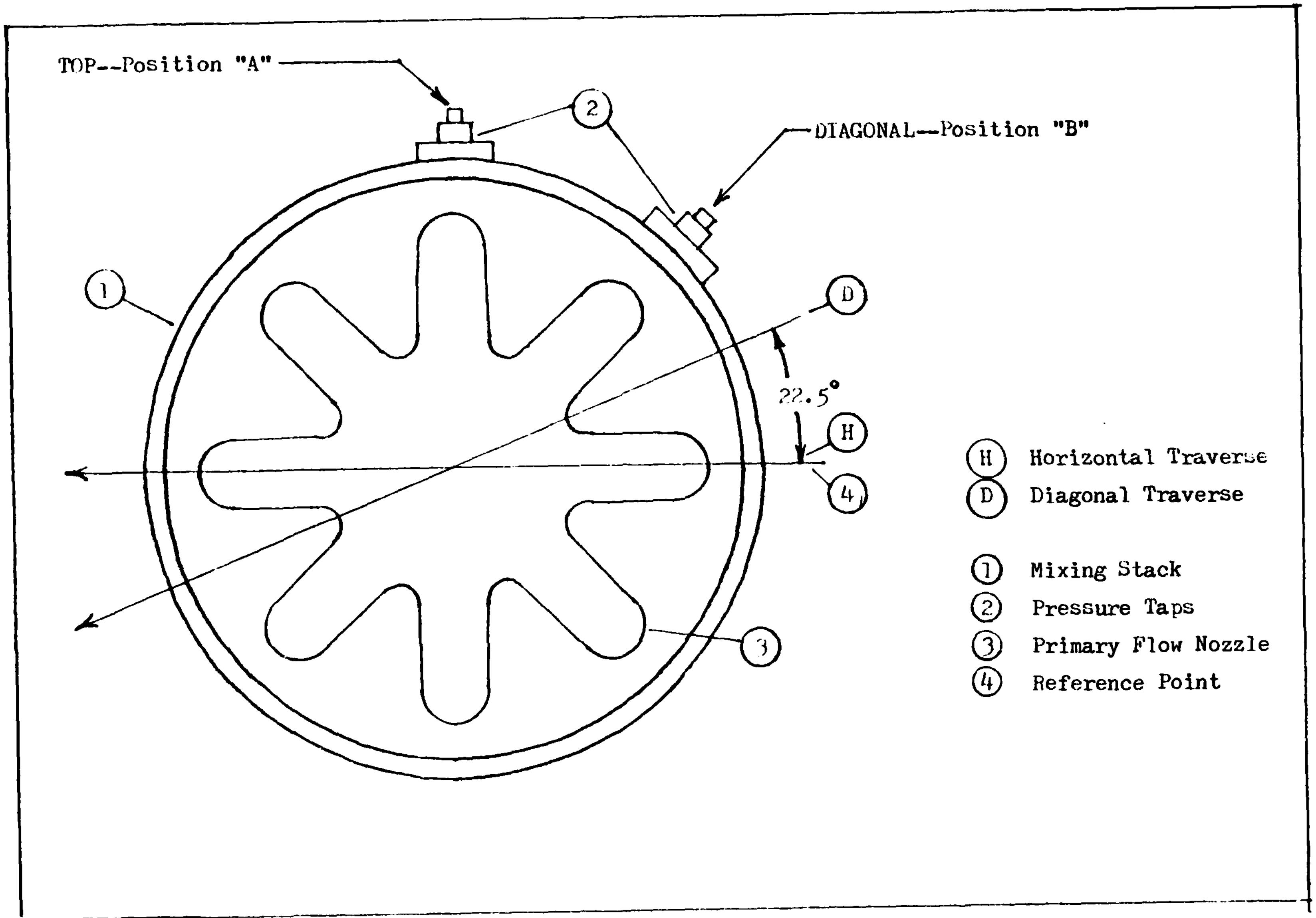


Figure 17. Mixing Stack Exit with Velocity Profile Directions and Pressure Tap Locations (Single Nozzle)

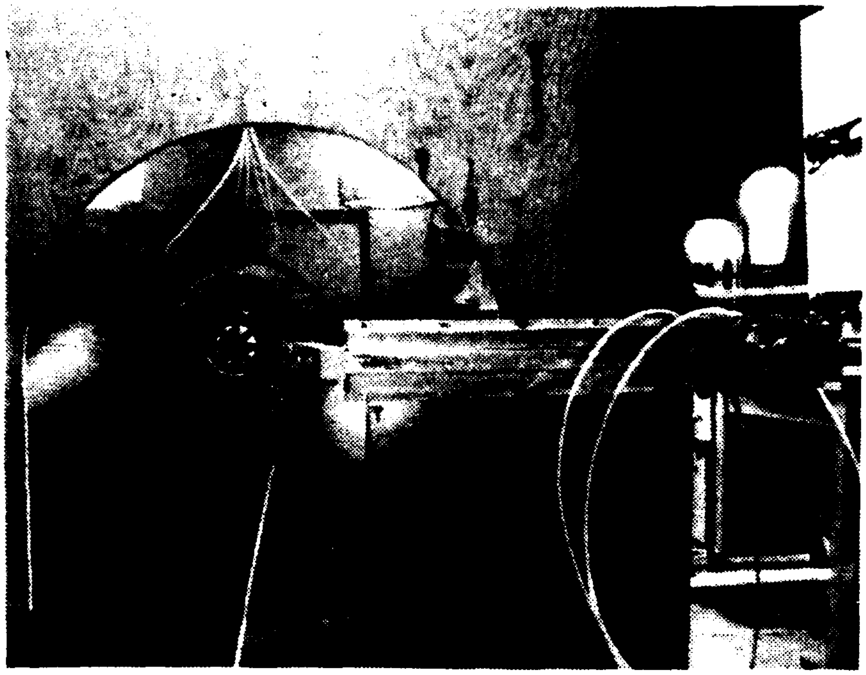


Figure 18. Velocity Traverse Bar and Mixing Stack

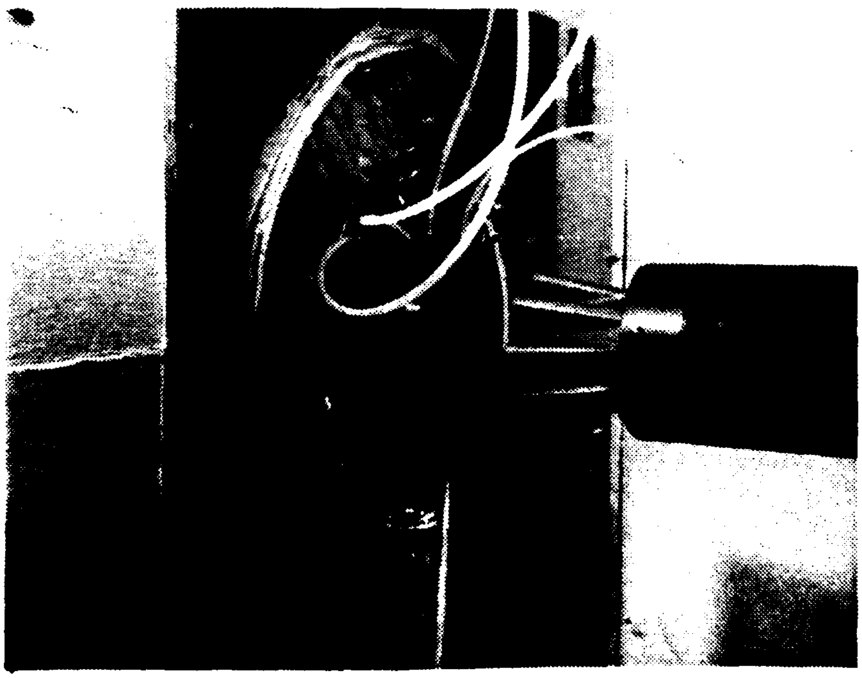
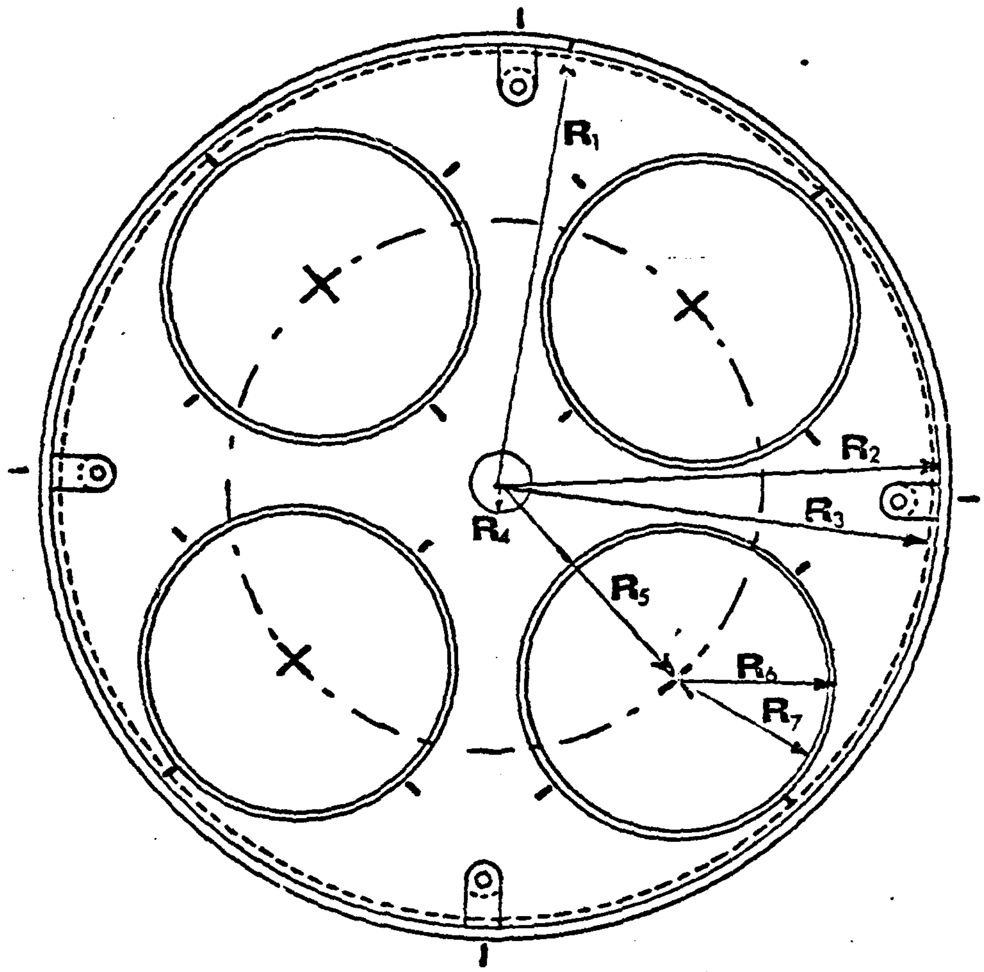


Figure 19. Mixing Stack with Pressure Taps and Air Seal



		Radii (Inches)	
1	Fixed Outer Ring	R_1= 5.750	R_6= 2.000
2	Rotating Base Plate	R_2= 5.600	R_7= 1.850
3	Recesses for Angled Nozzles	R_3= 5.400	
4	Locking Cams	R_4= 0.375	
		R_5= 3.200	

Figure 20. Dimensions of the Four Nozzle Rotatable Base Plate

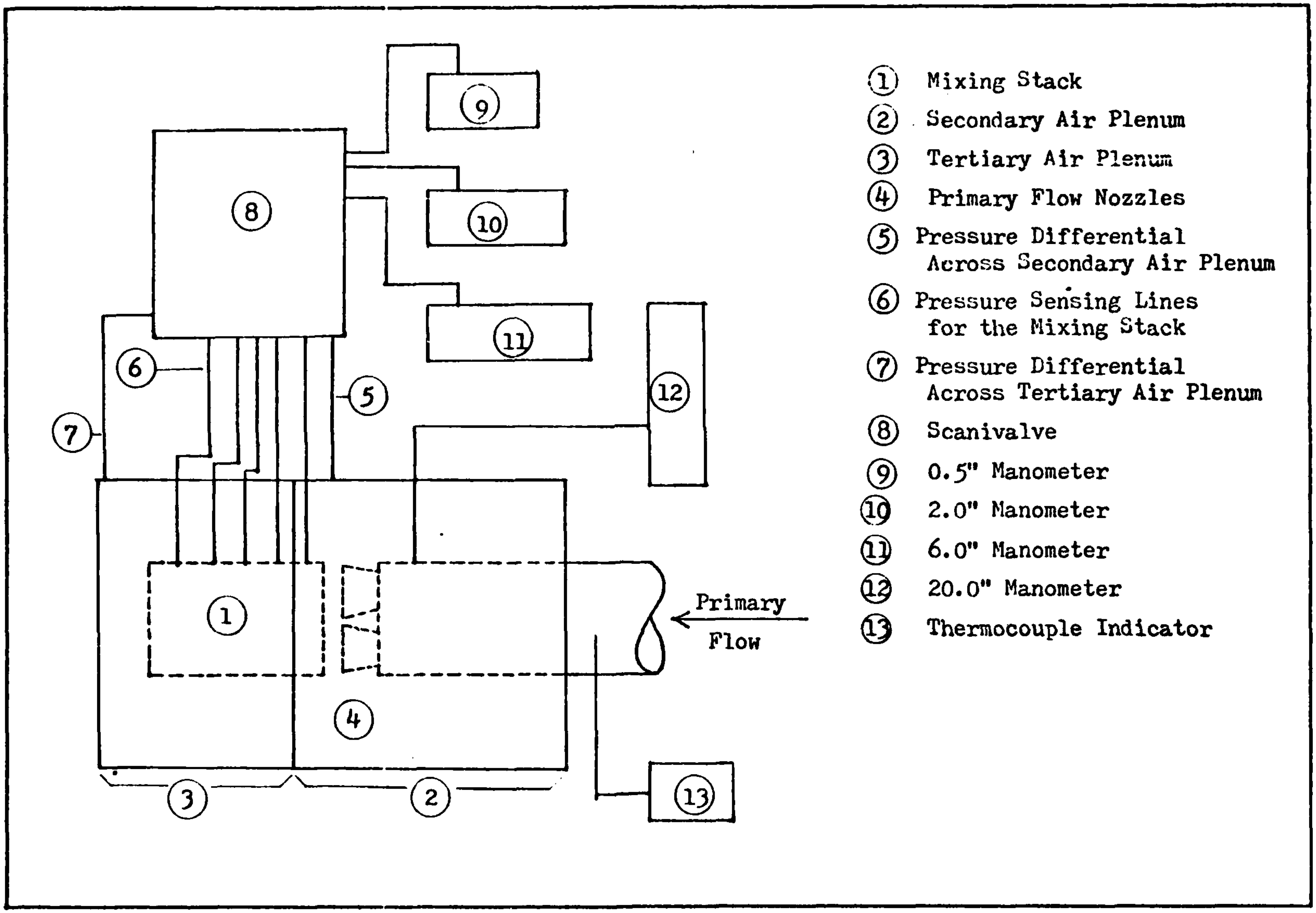


Figure 21. Schematic of Instrumentation

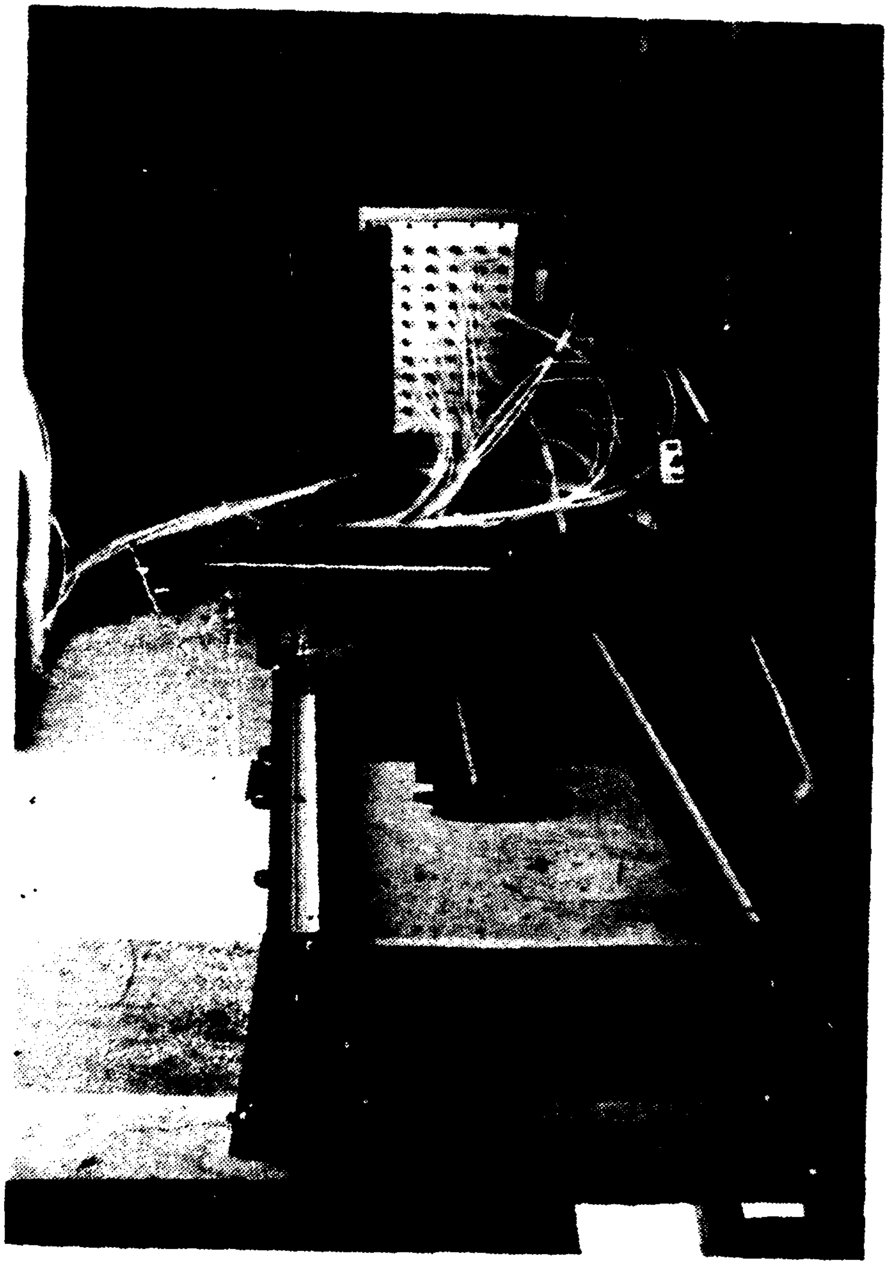


Figure 22. Instrumentation

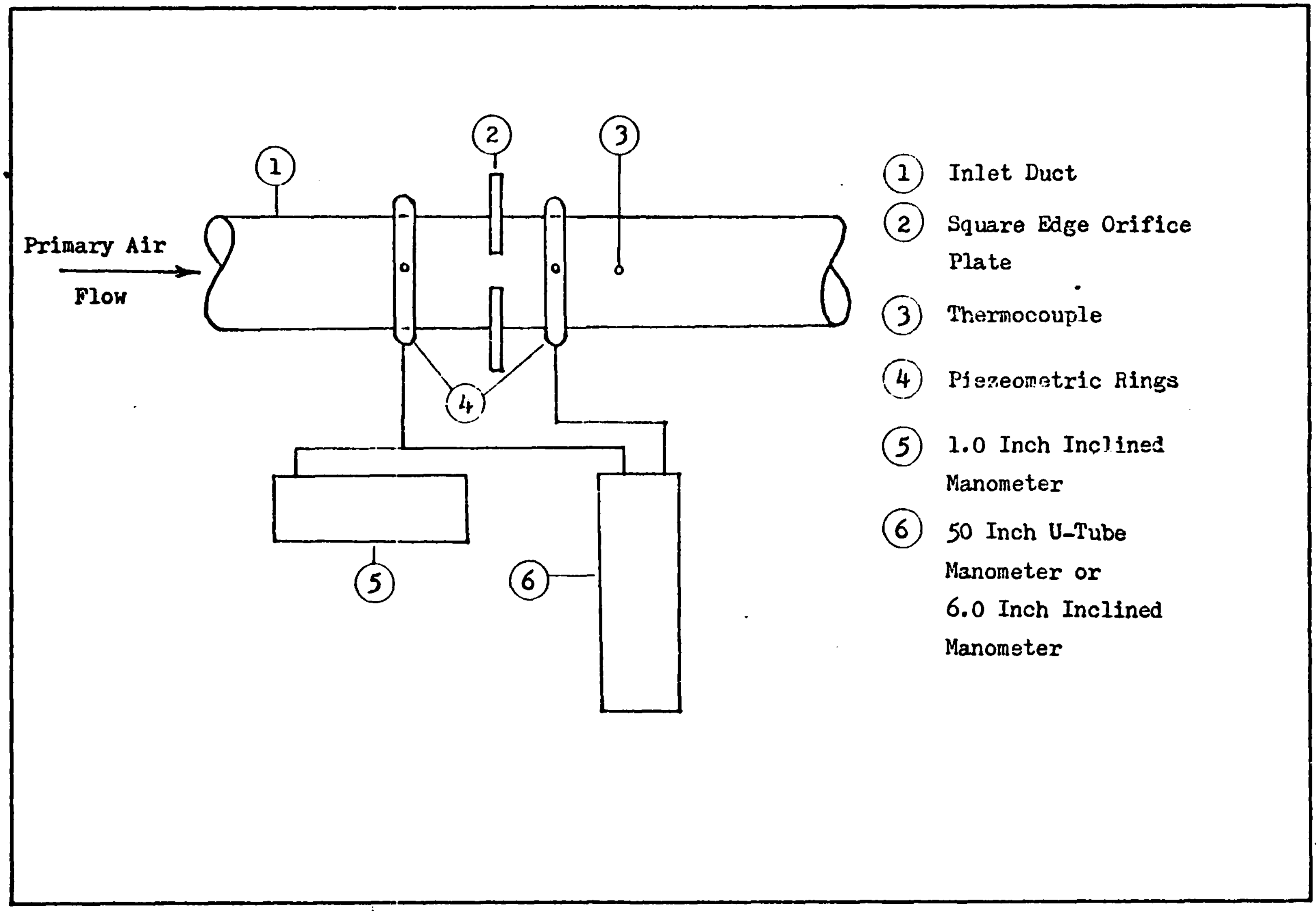


Figure 23. Schematic of Instrumentation for Primary Air Flow Measurement

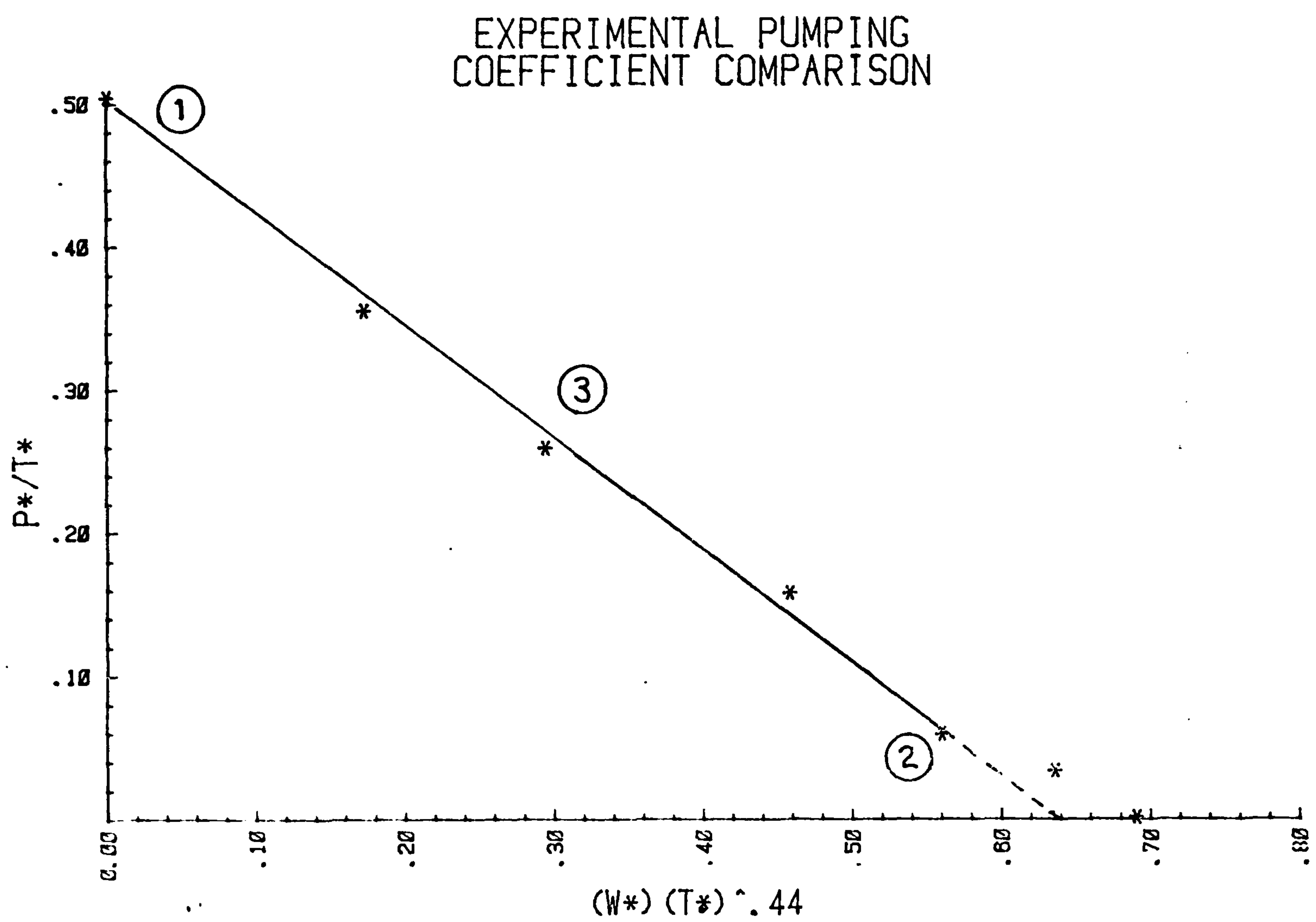


Figure 24. Sample Pumping Coefficient Plot

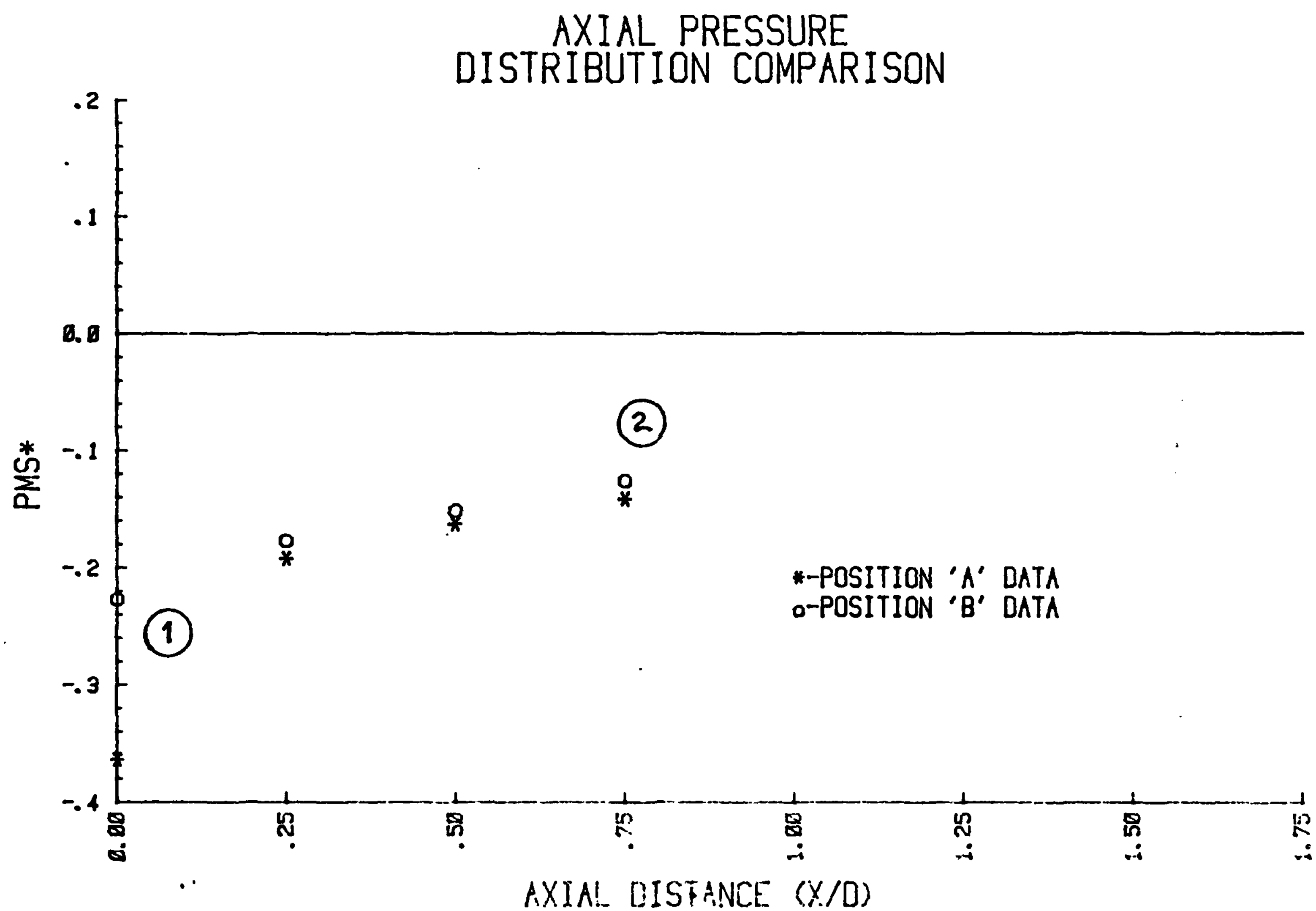


Figure 25. Sample Mixing Stack Pressure Distribution Plot

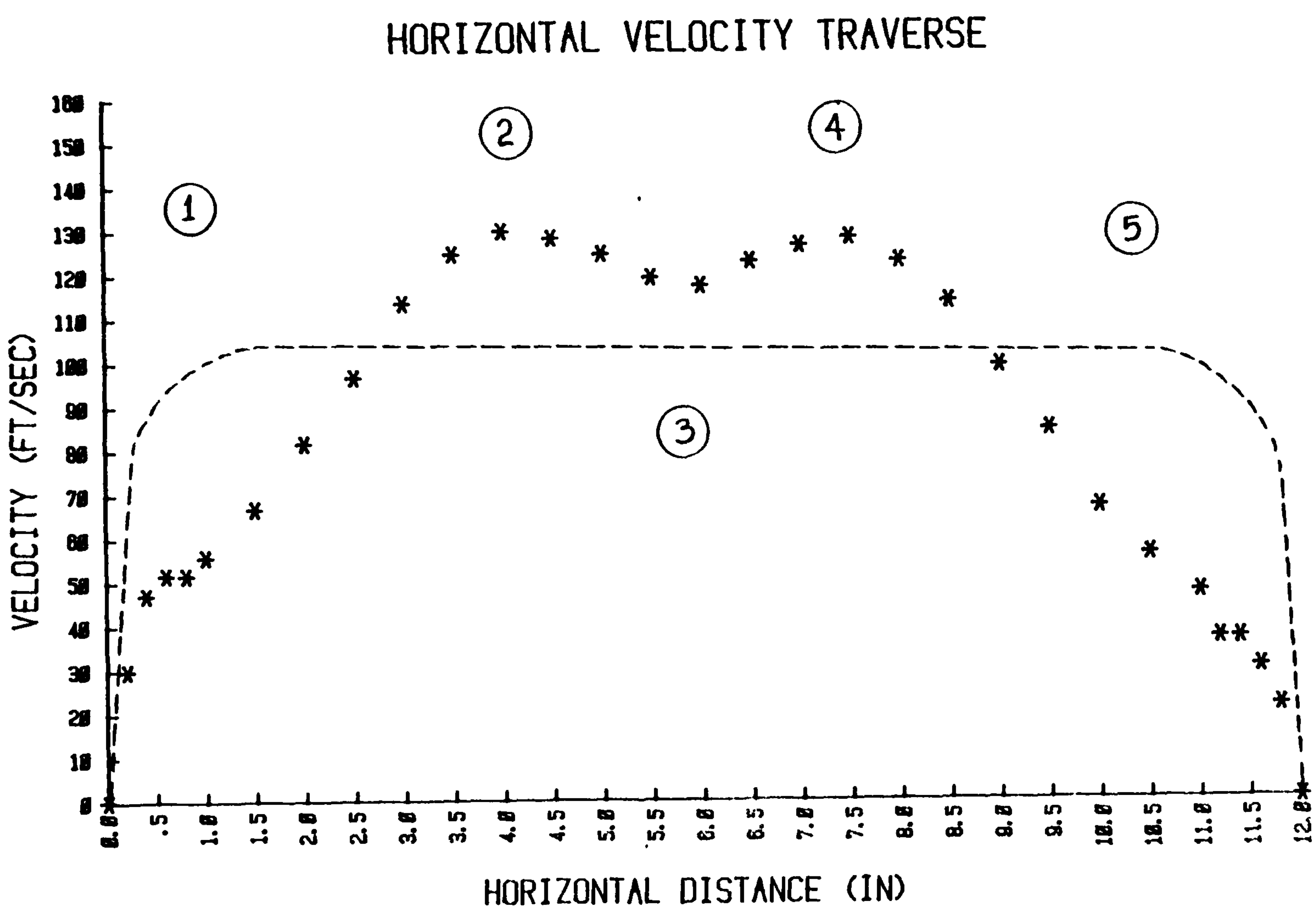


Figure 26. Sample Horizontal Velocity Profile Plot

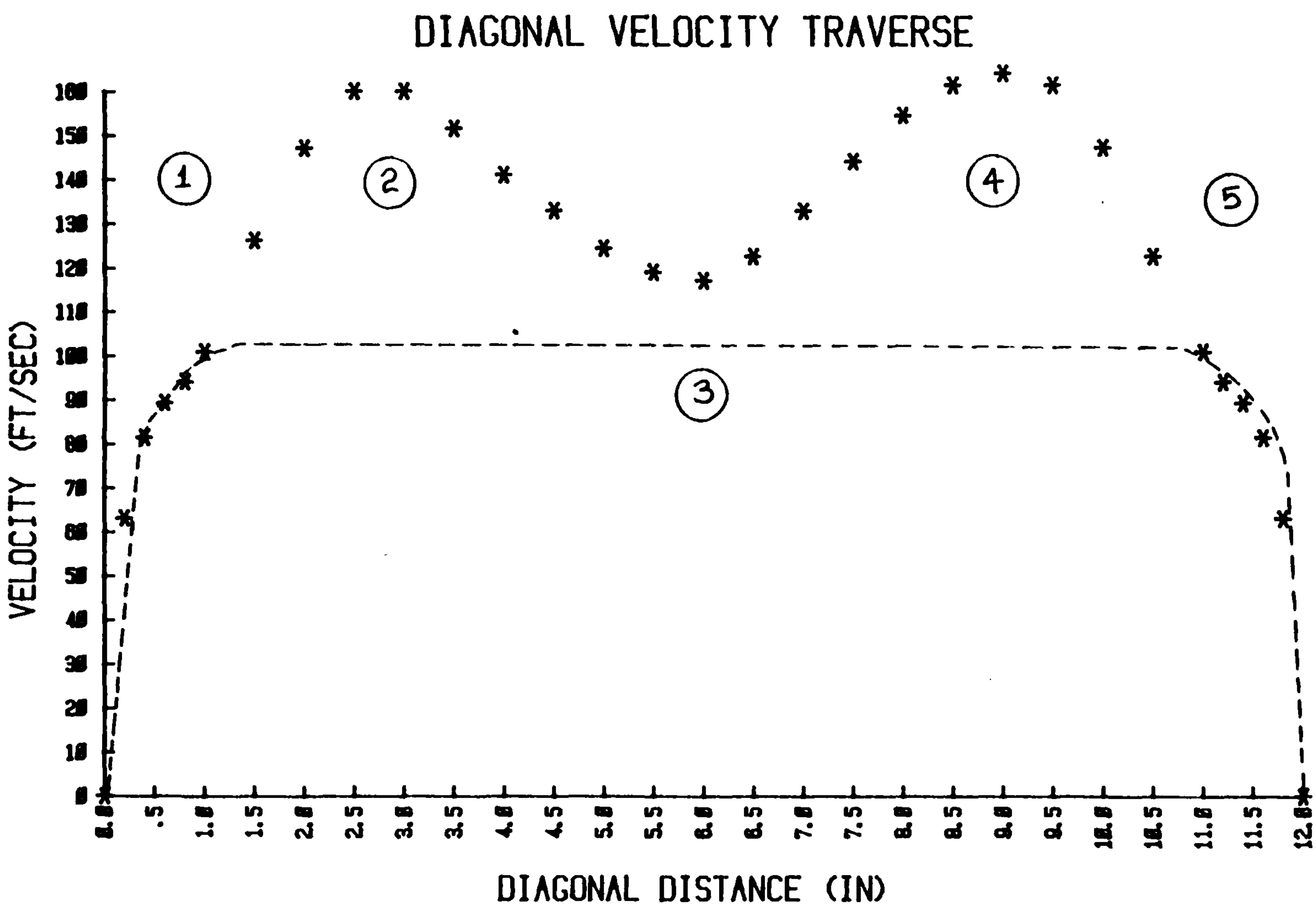


Figure 27. Sample Diagonal Velocity Profile Plot

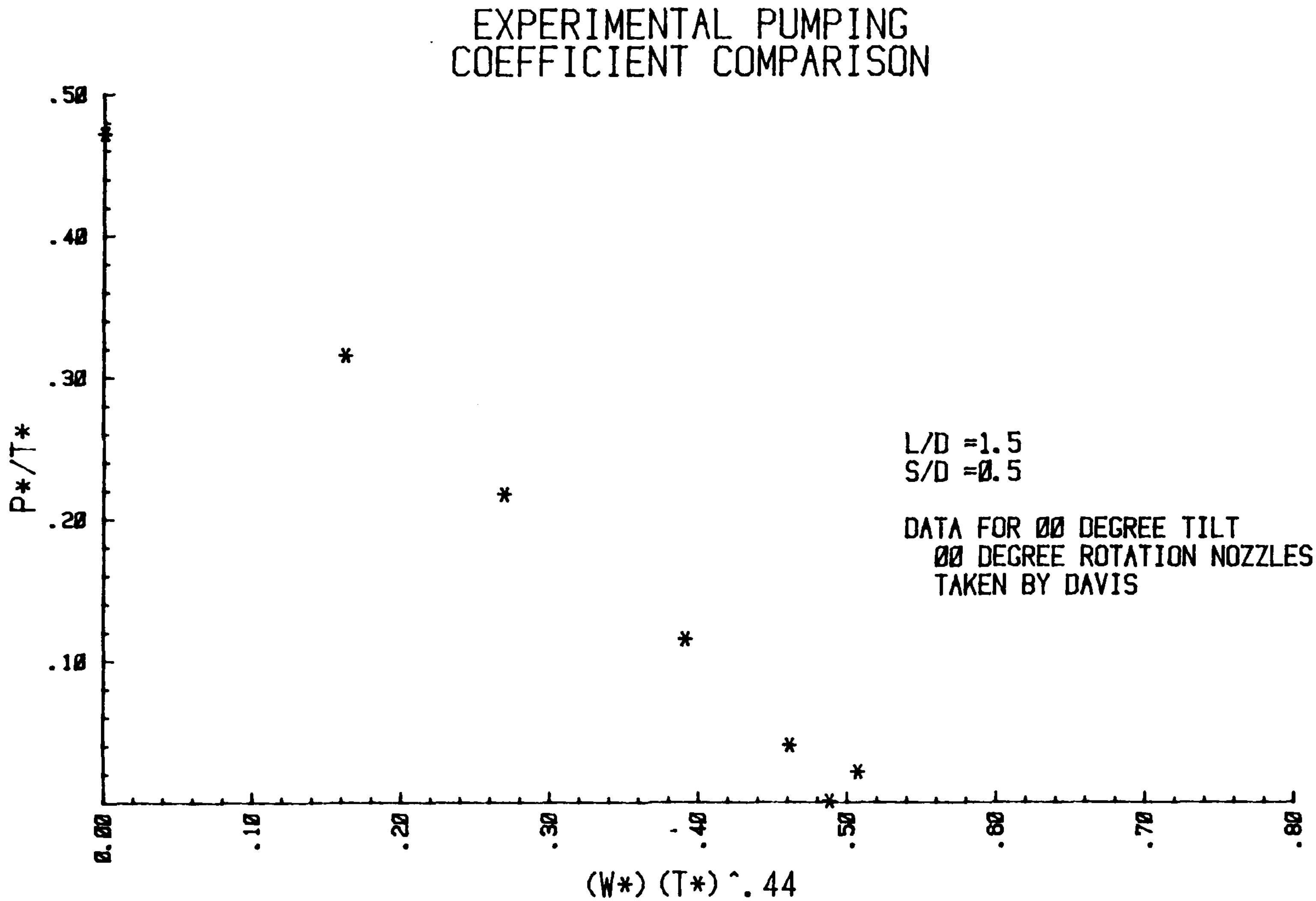


Figure 28. Performance Plots for L/D = 1.5 Straight Nozzles

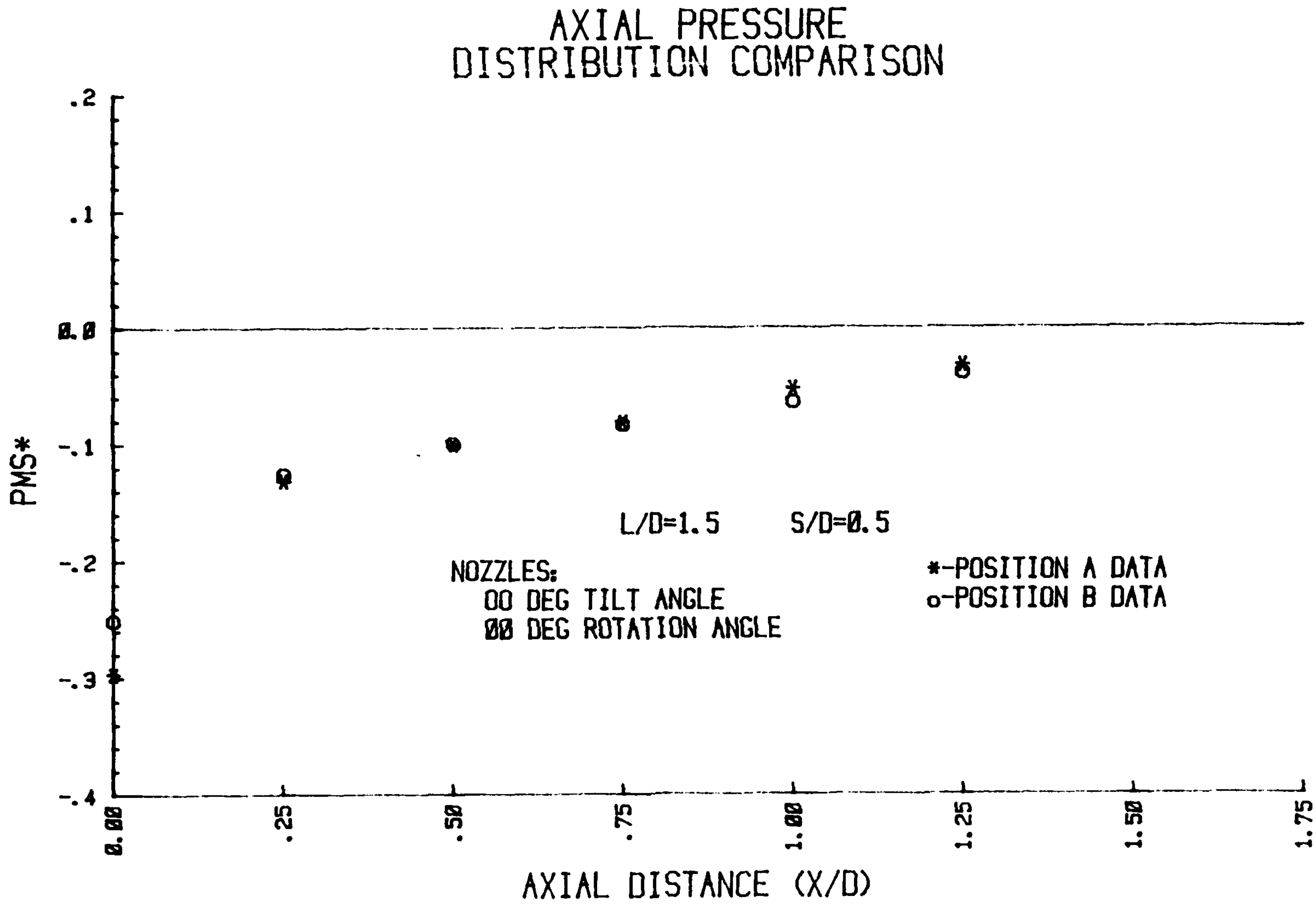


Figure 28. (contd) MSD

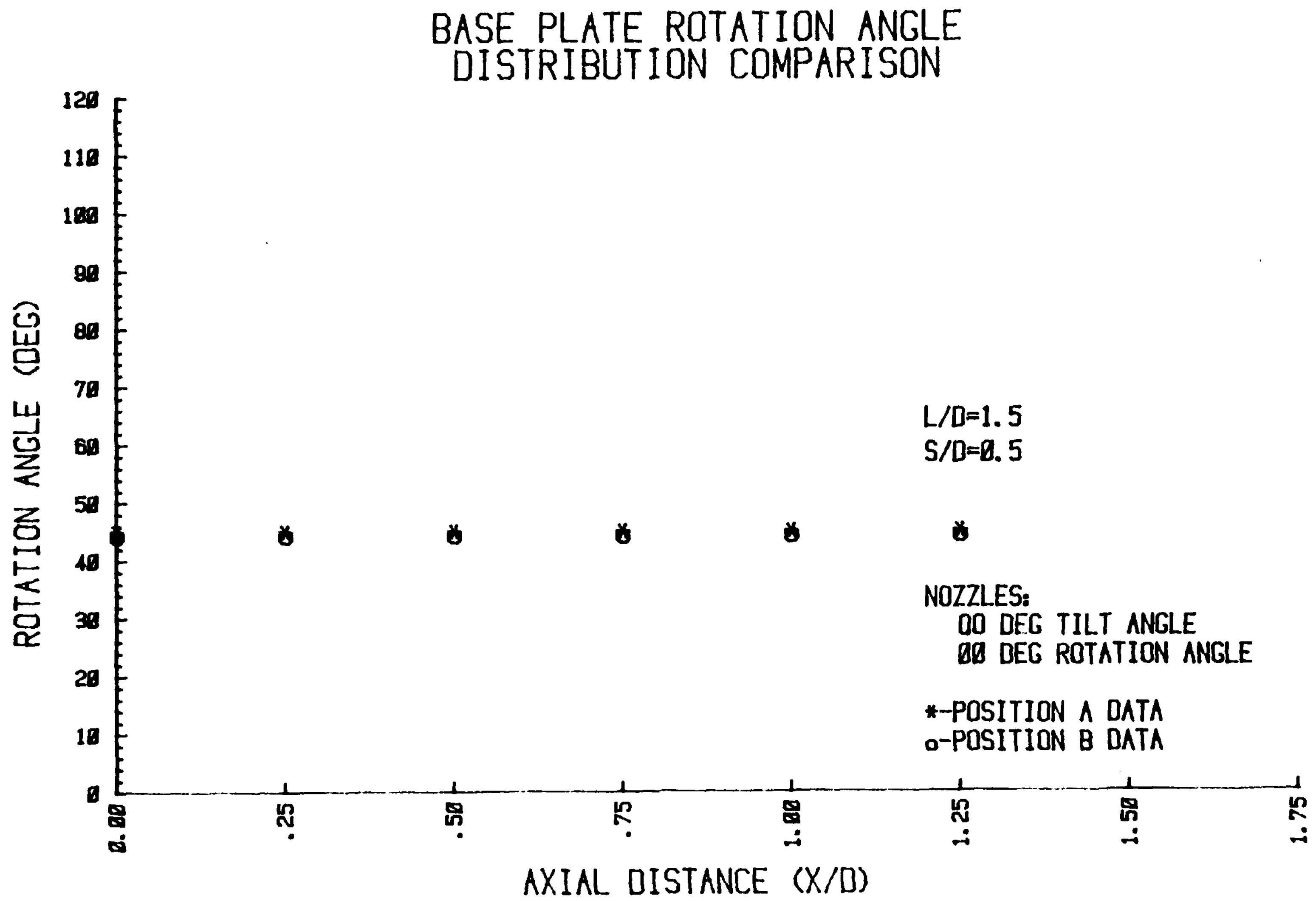


Figure 28. (contd) MSD

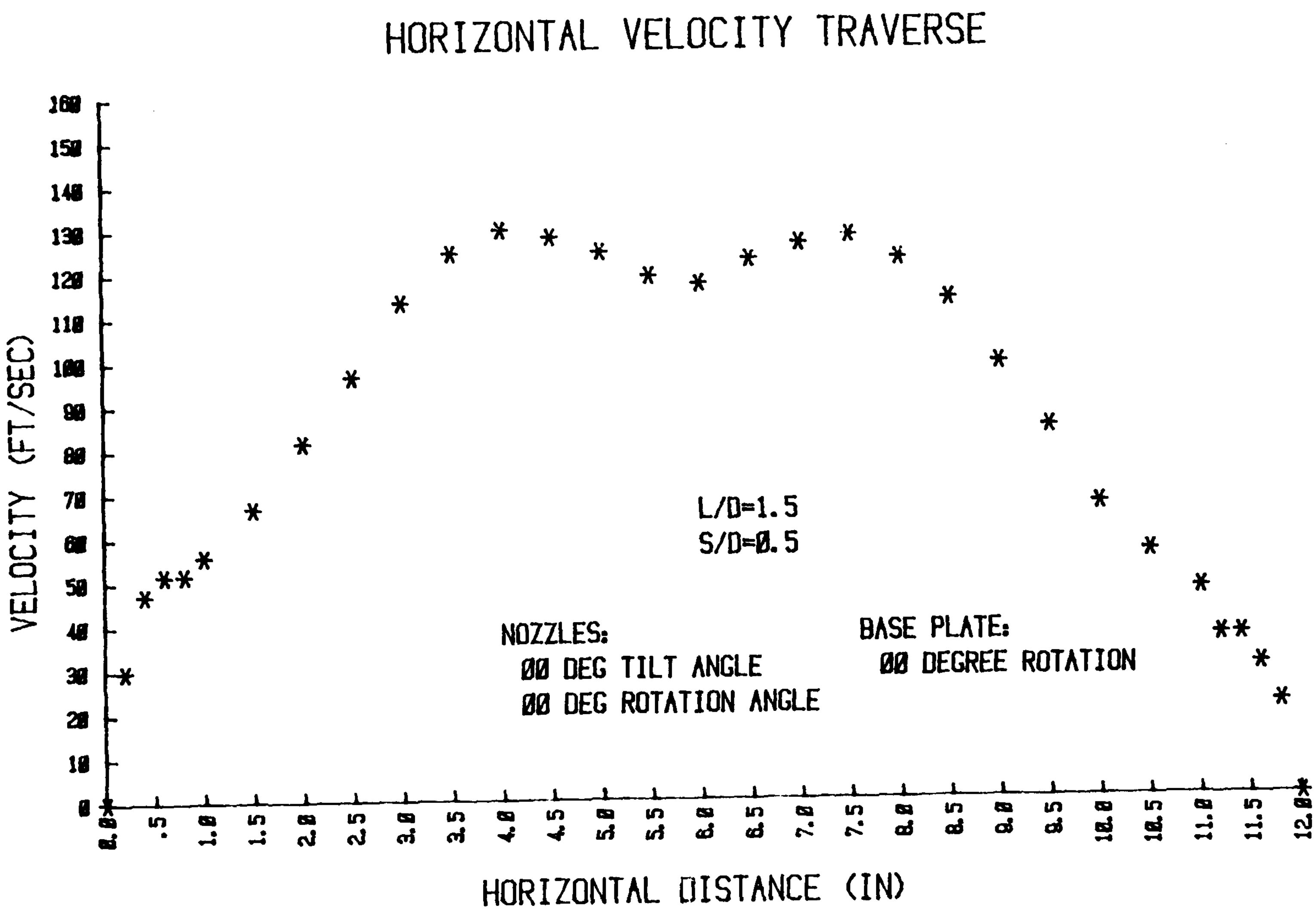


Figure 28. (contd) VTD

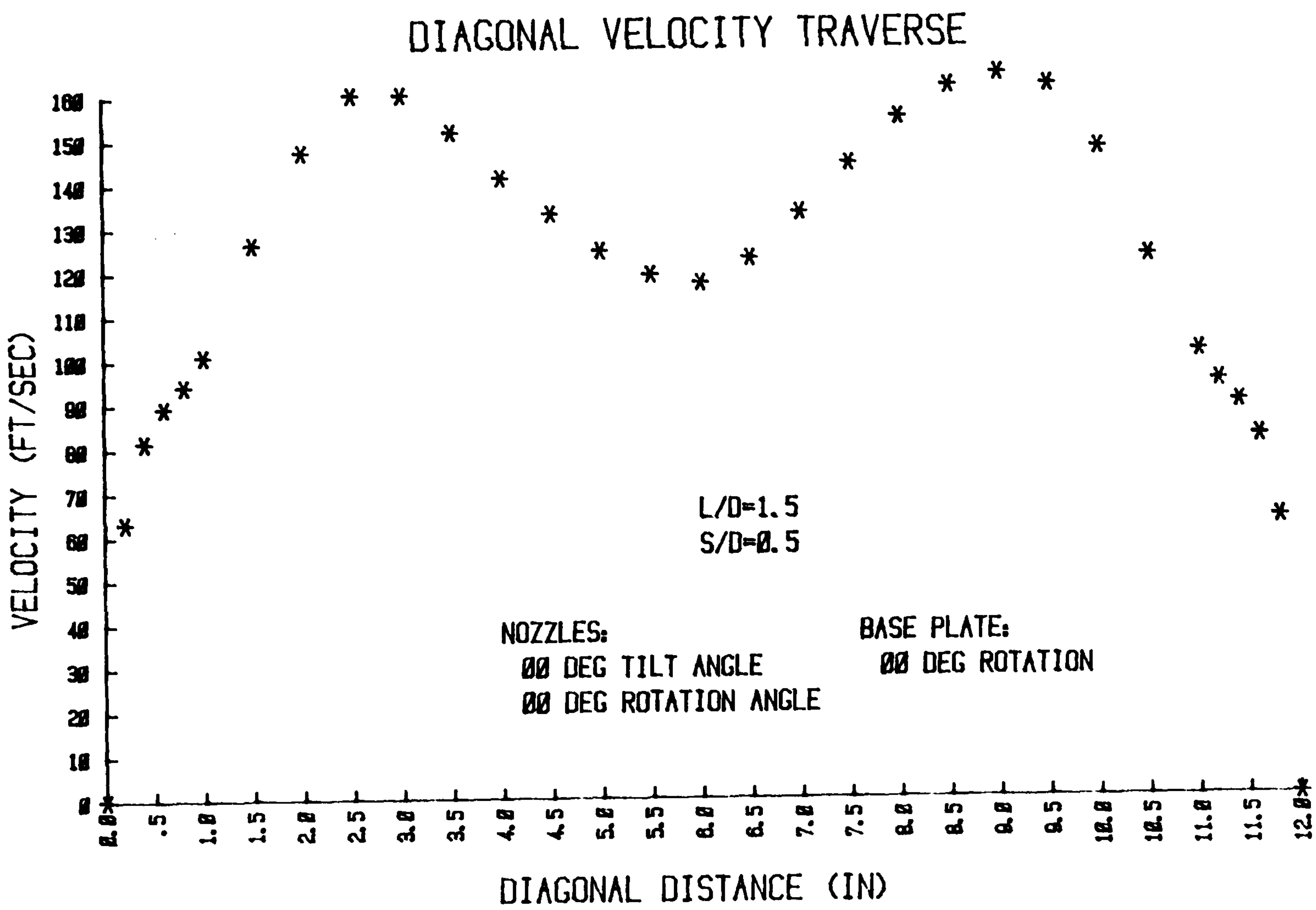


Figure 28. (contd) VTD

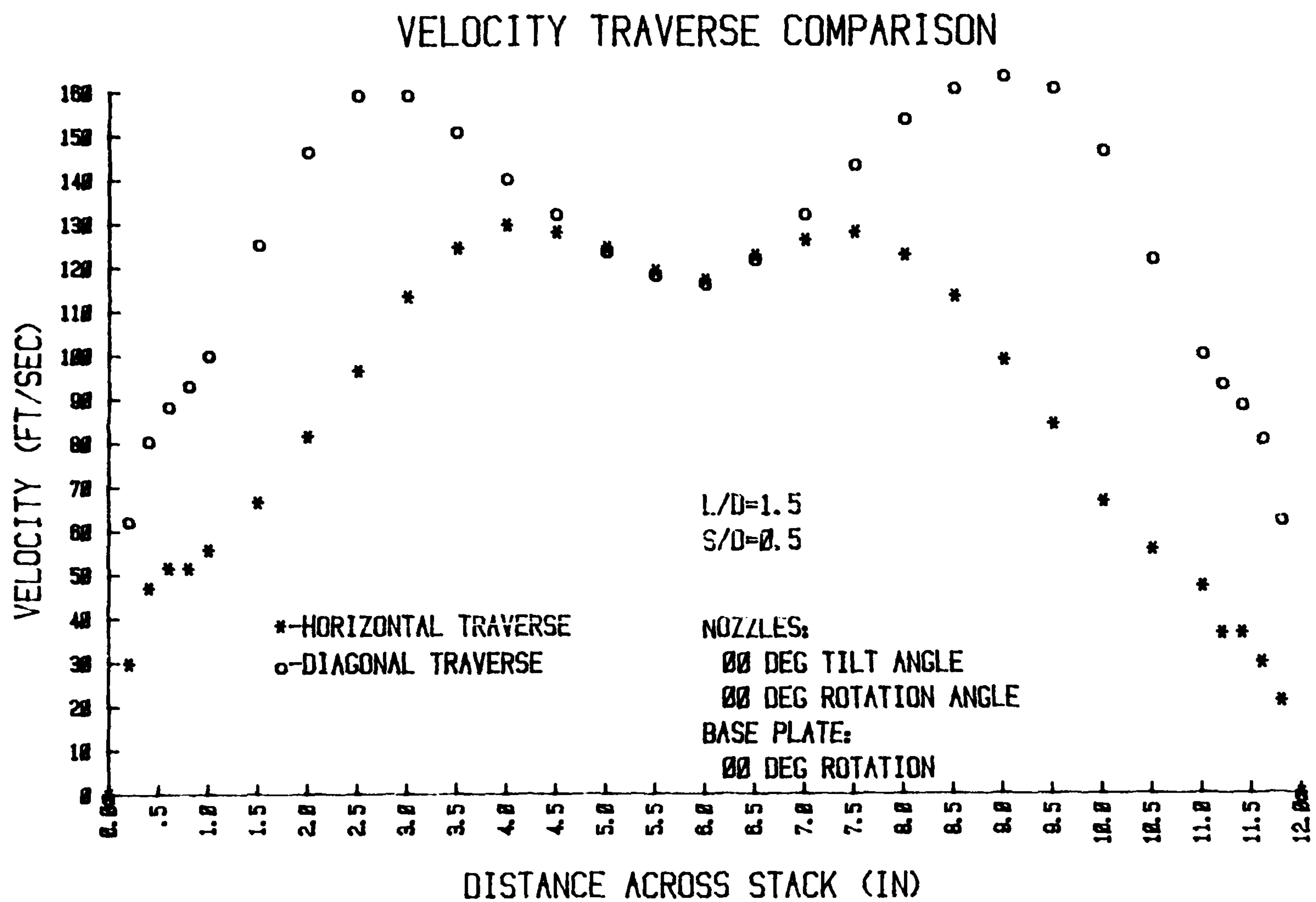


Figure 28. (contd) VTD Comparison

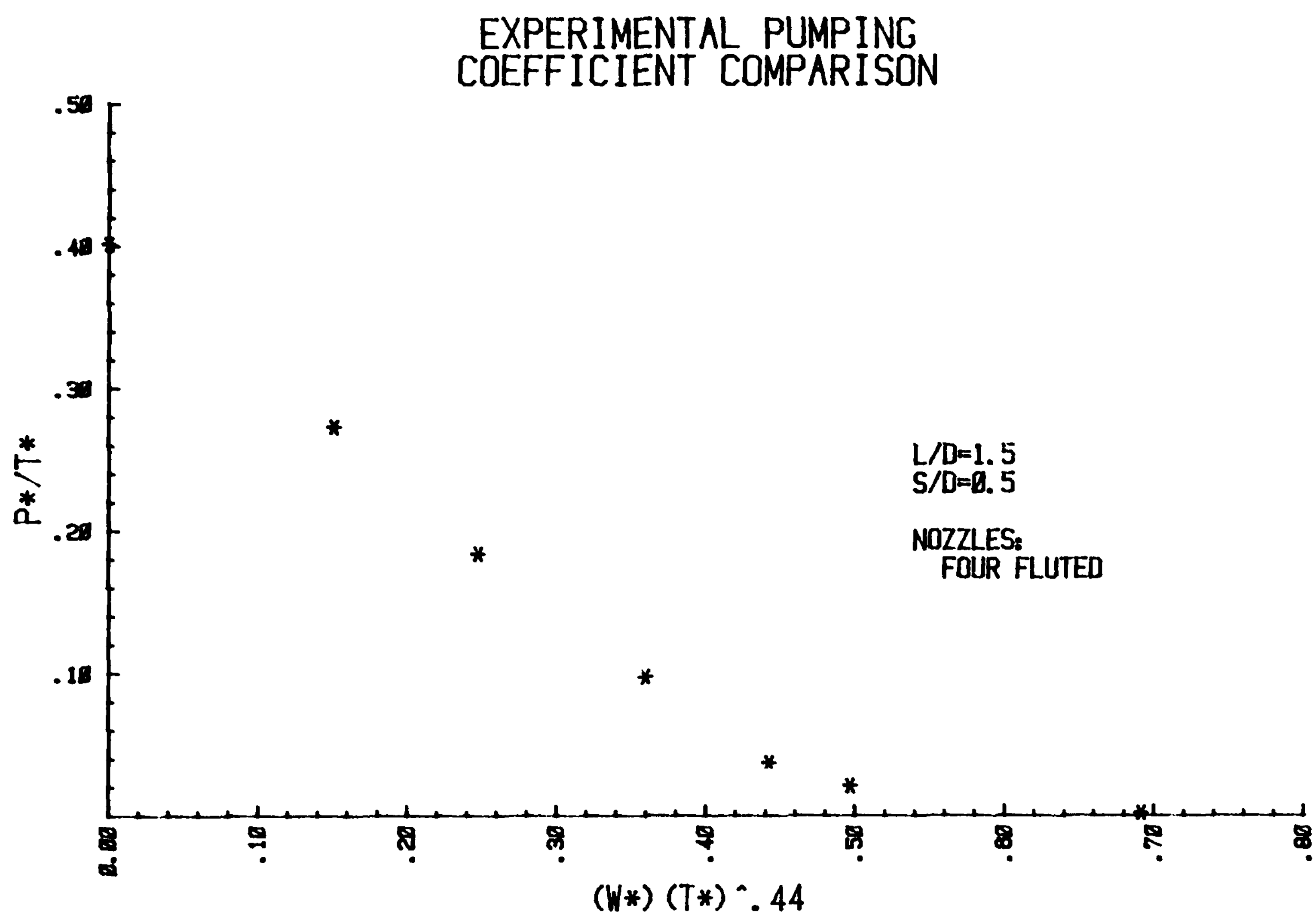


Figure 29. Four Fluted Nozzles (Full Run)

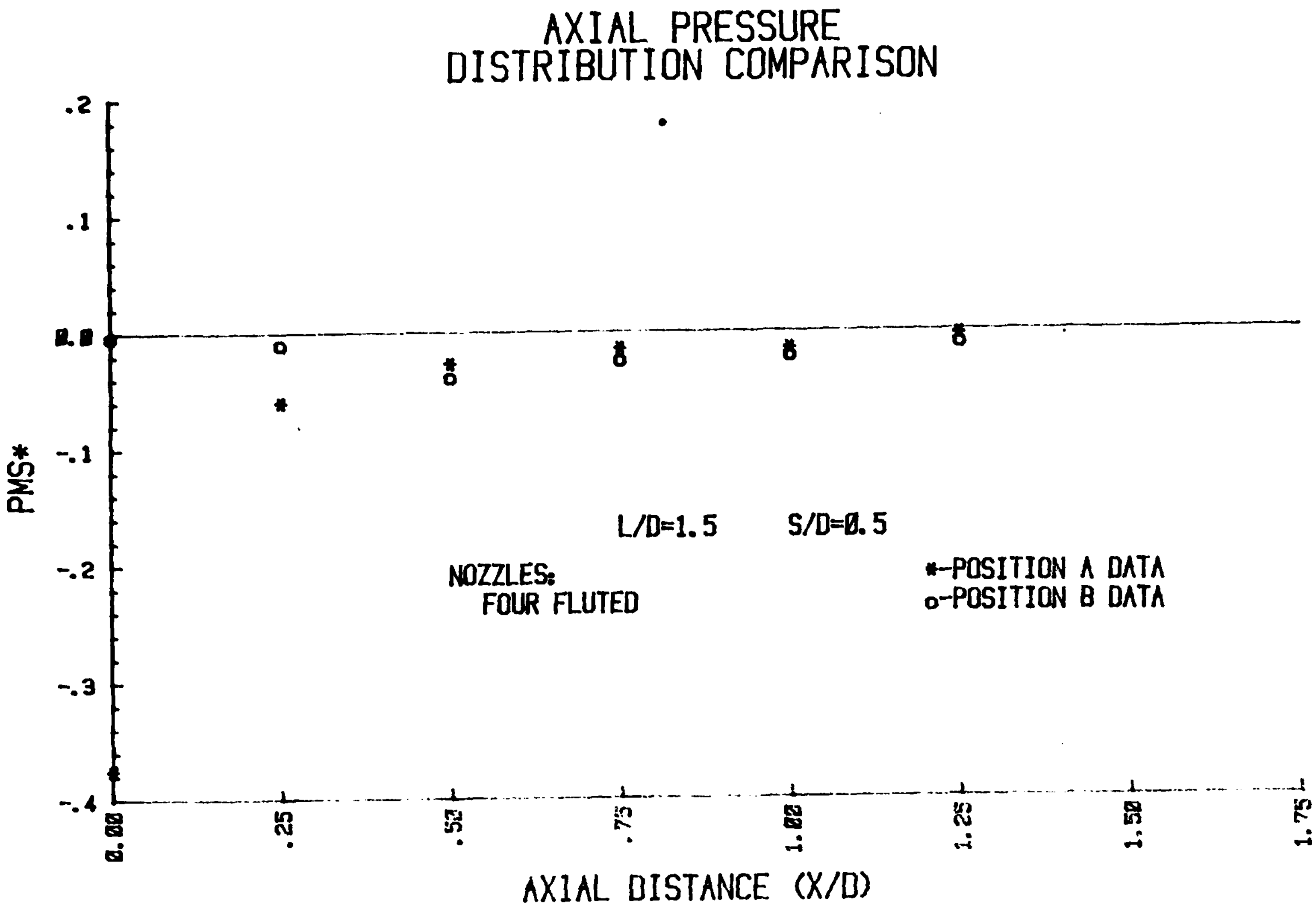


Figure 29. (contd) MSD

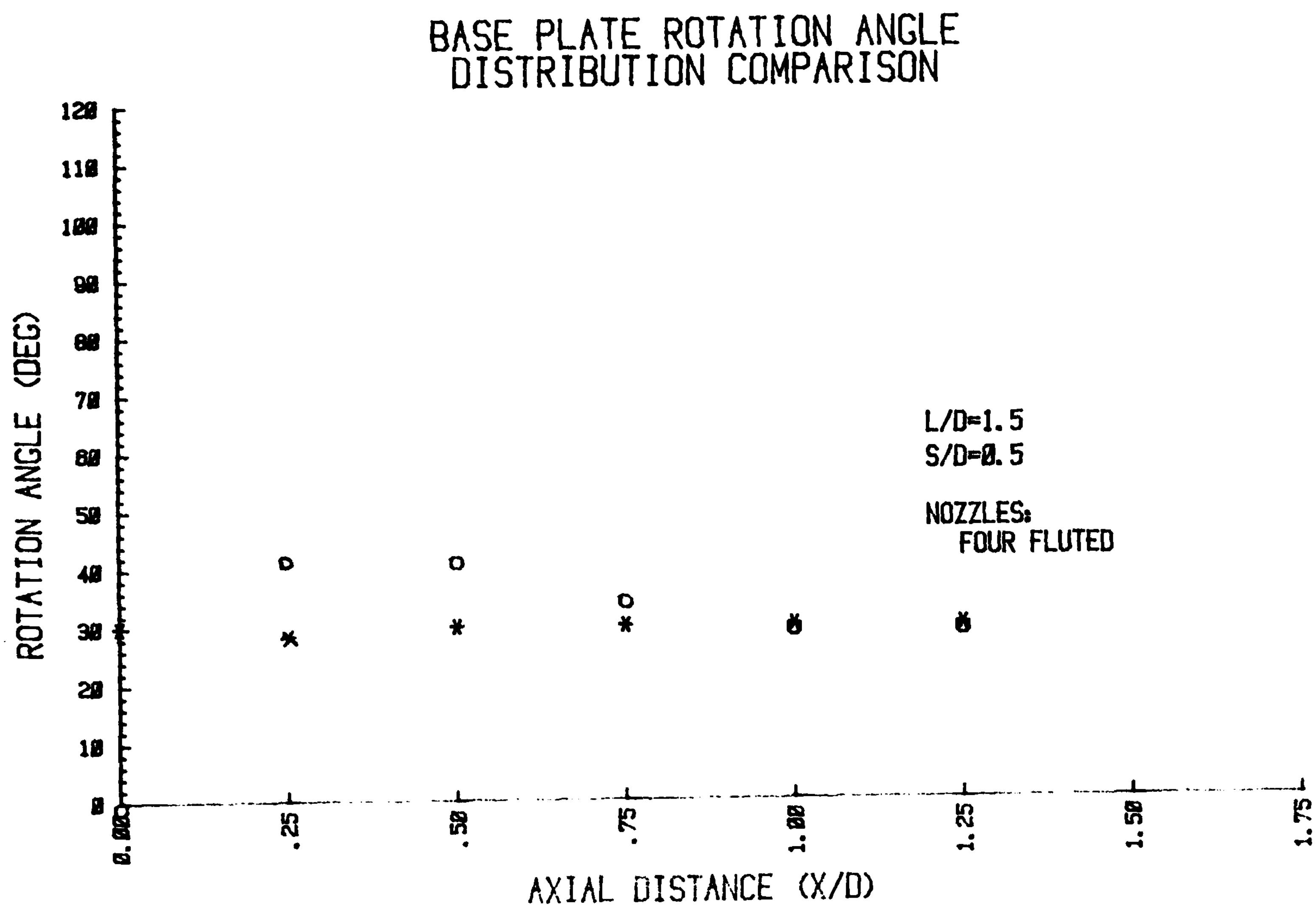


Figure 29. (contd) MSD

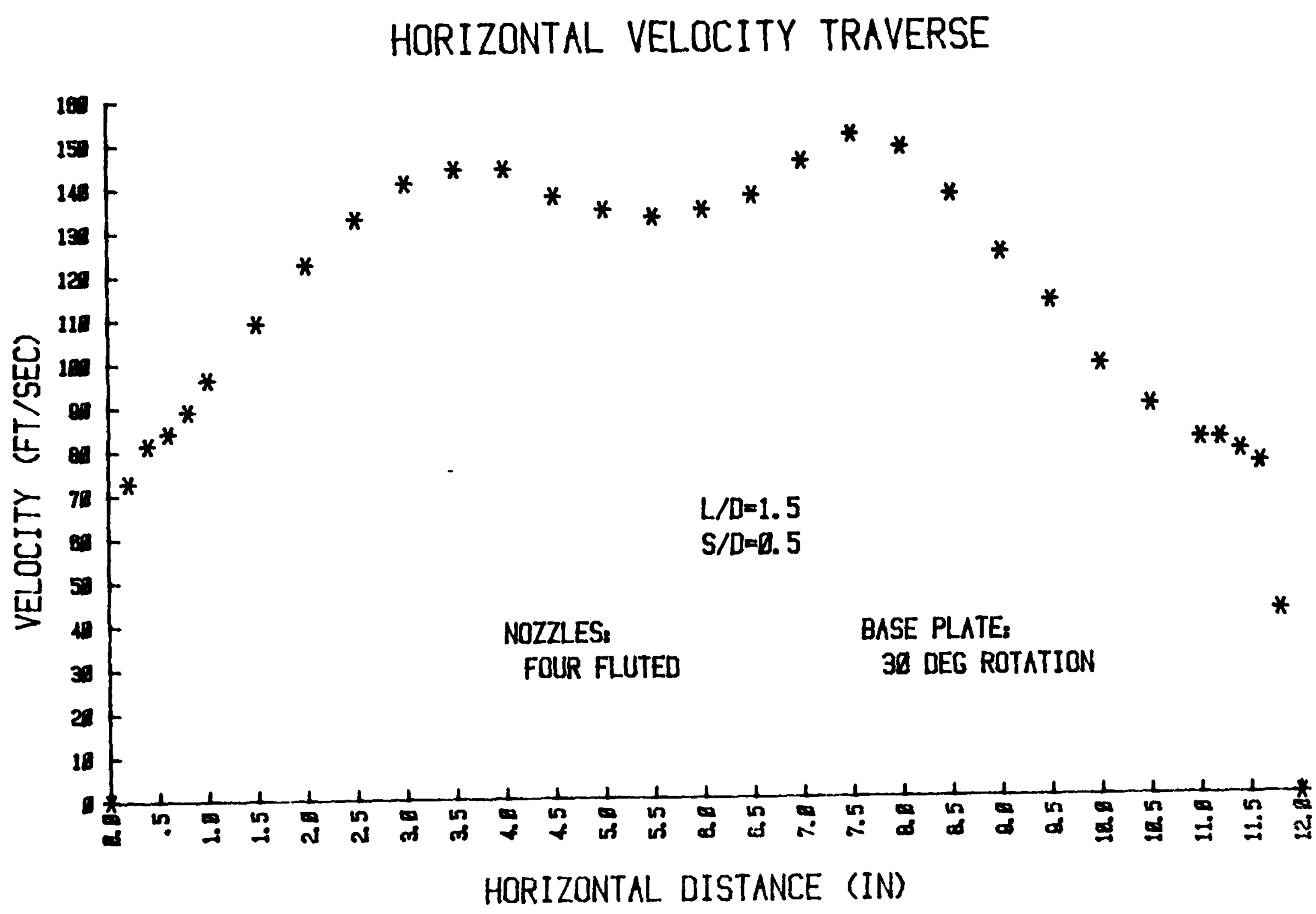


Figure 29. (contd) VTD

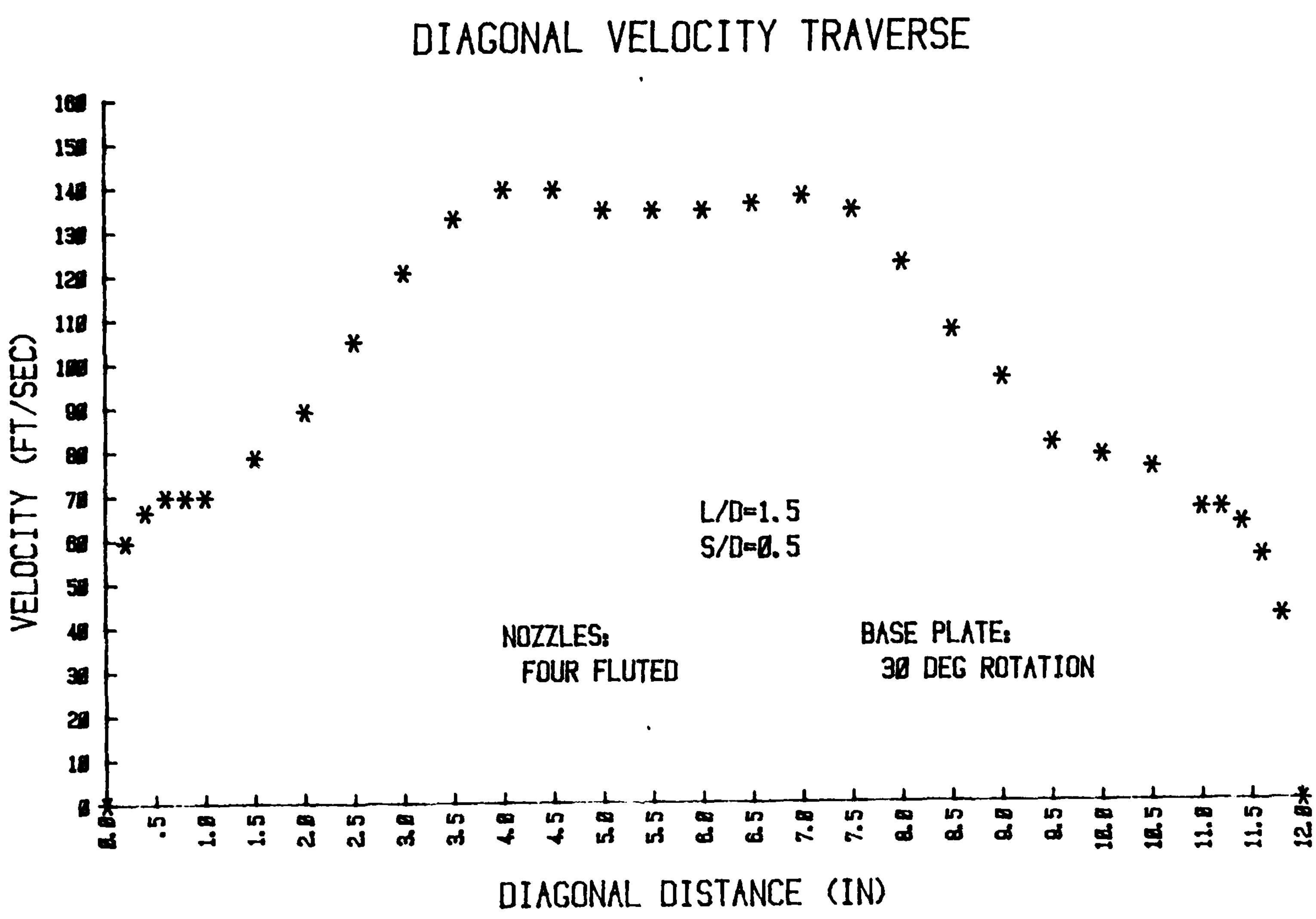


Figure 29. (contd) VTD

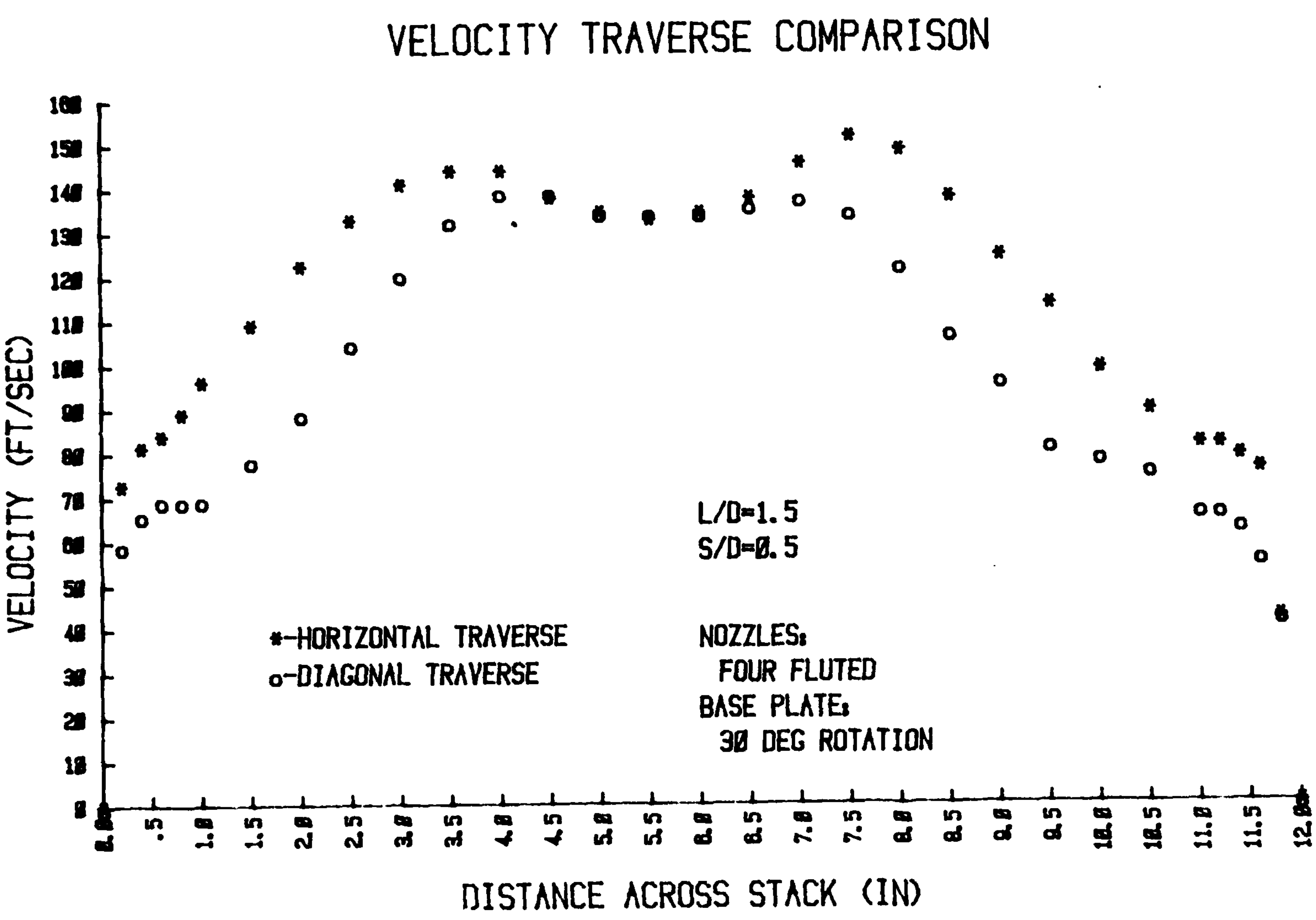


Figure 29. (contd) VTD Comparison

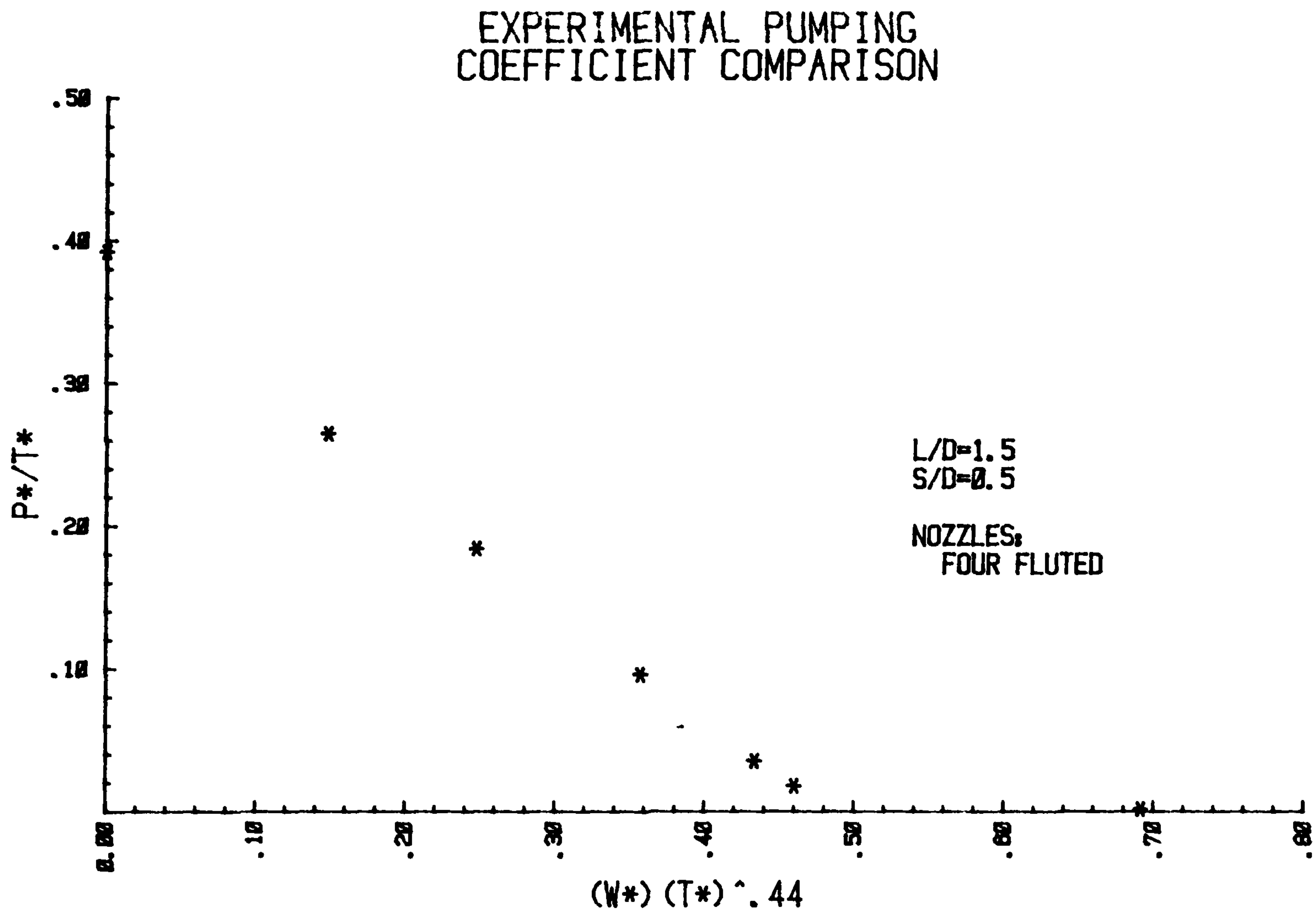


Figure 30. Four Fluted Nozzles (Symmetry Run)

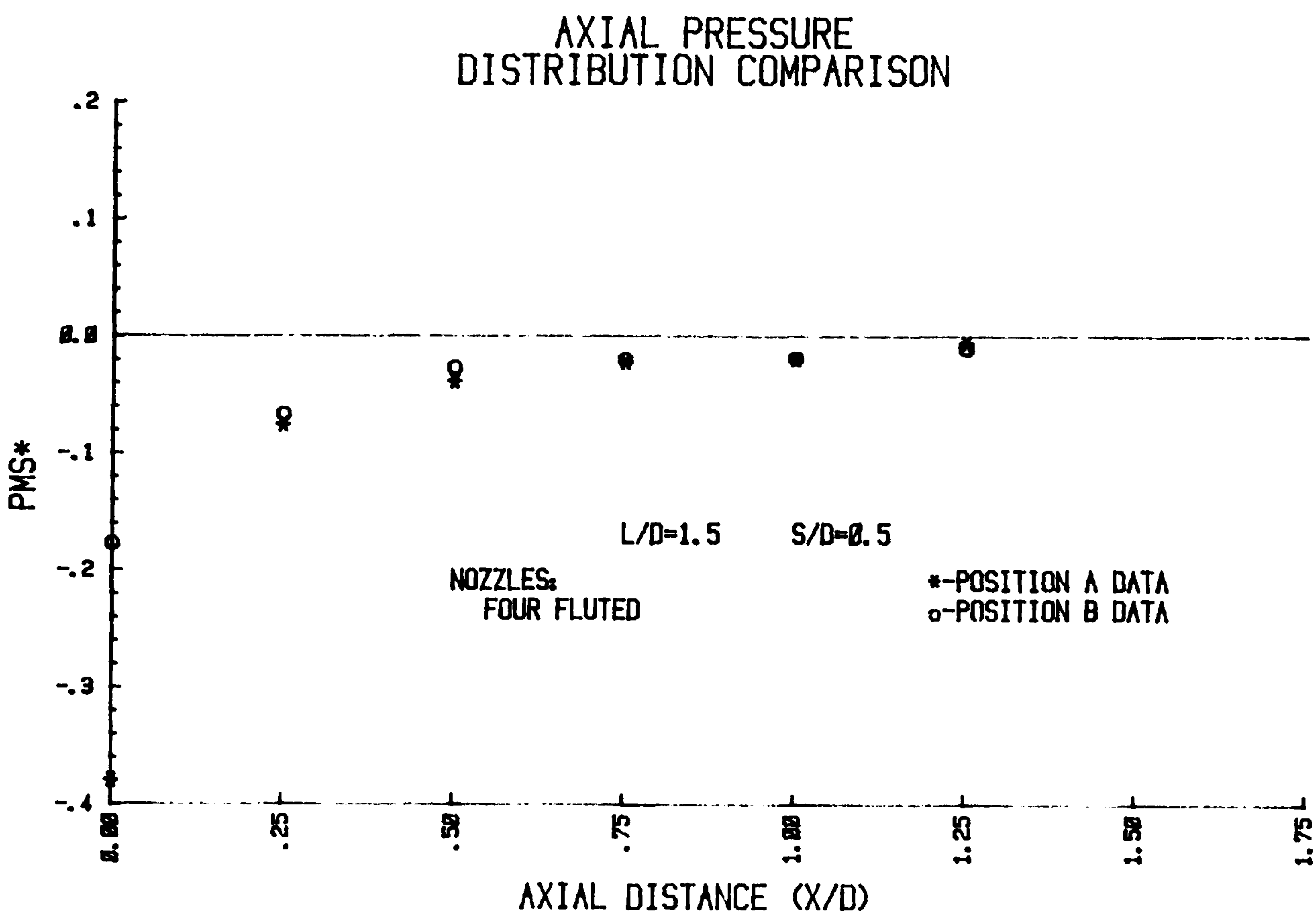


Figure 30. (contd) MSD

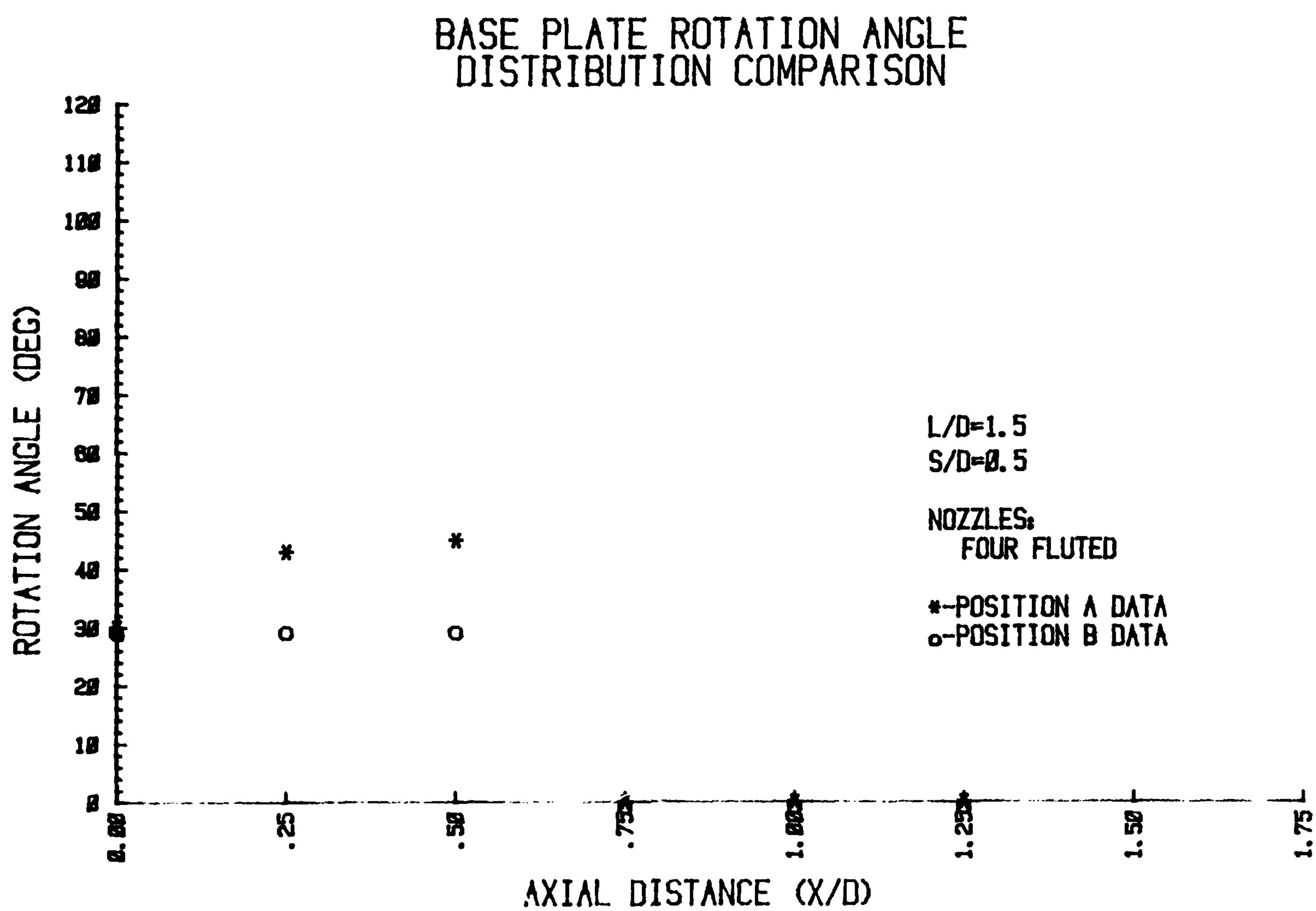


Figure 30. (contd) MSD

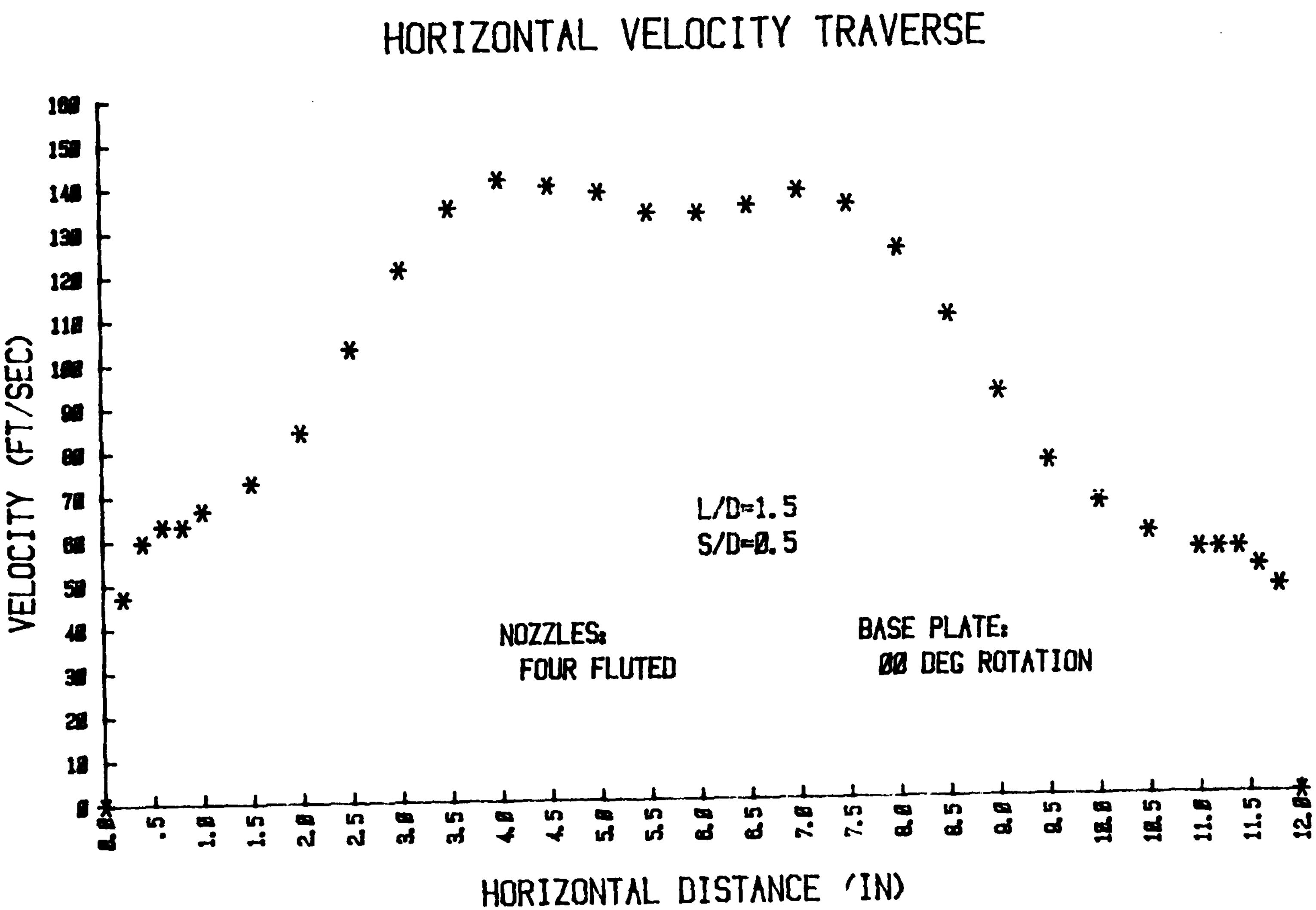


Figure 30. (contd) VTD

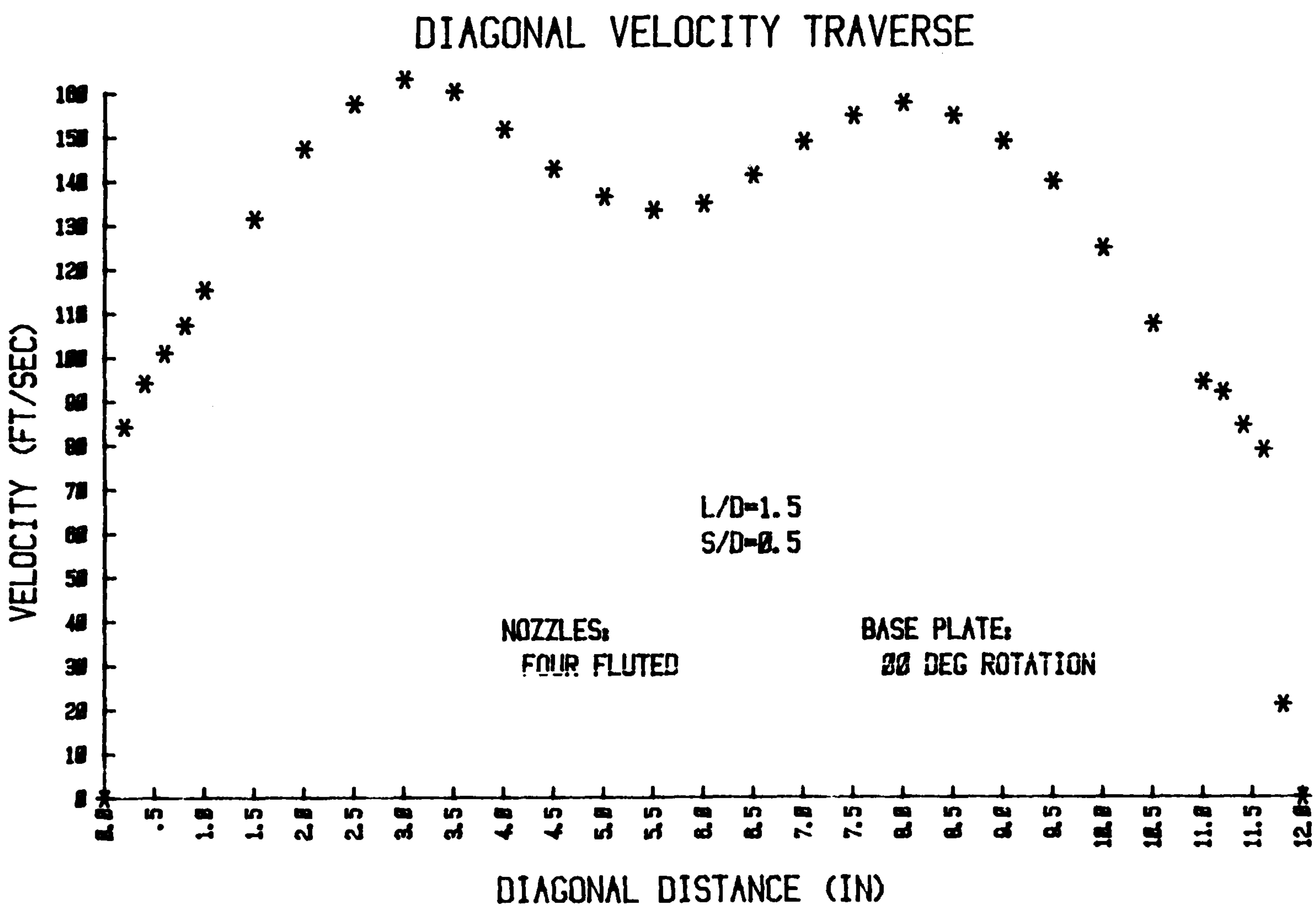


Figure 30. (contd) VTD

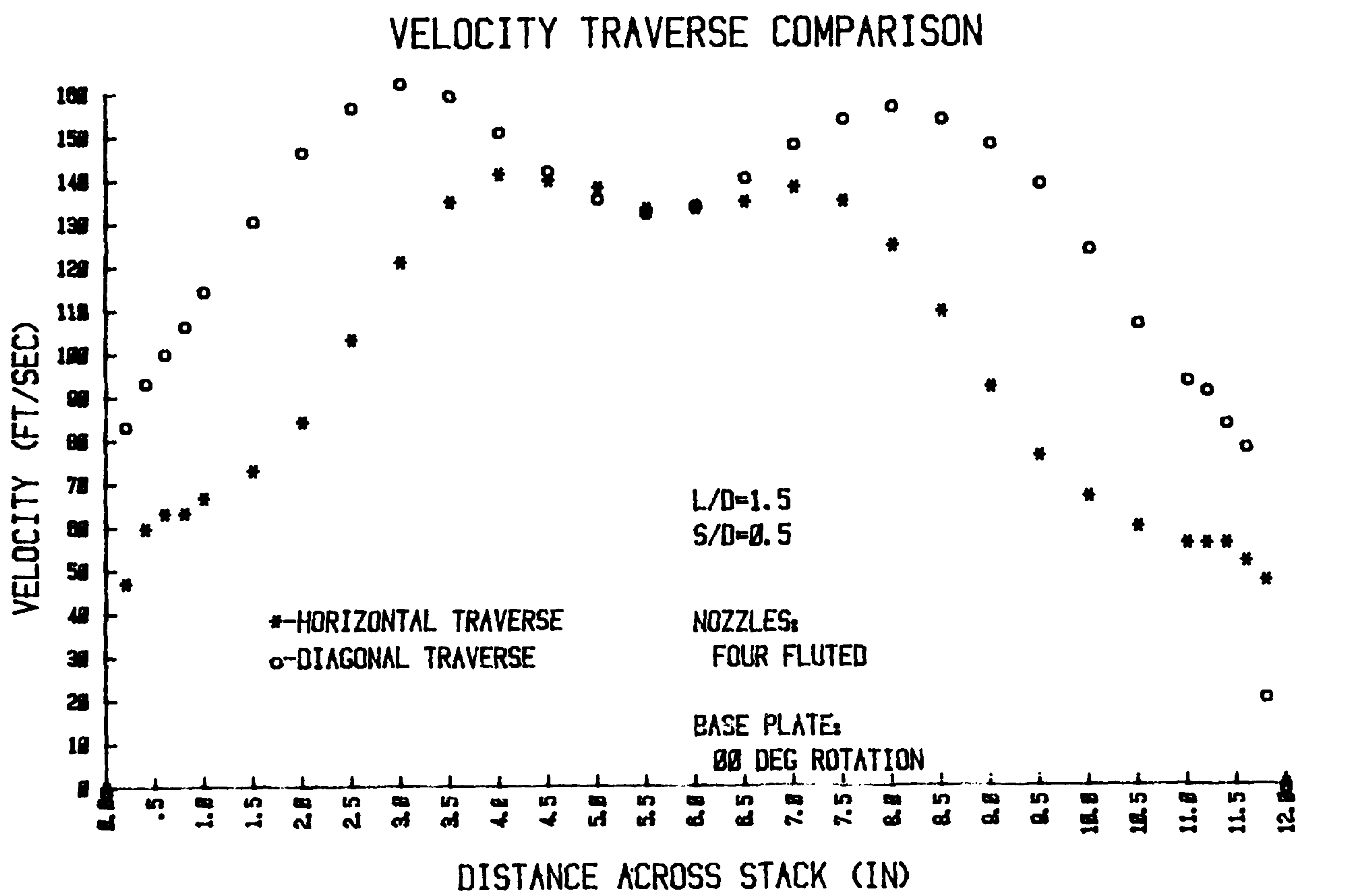


Figure 30. (contd) VTD Comparison: 0^{o} Rotation

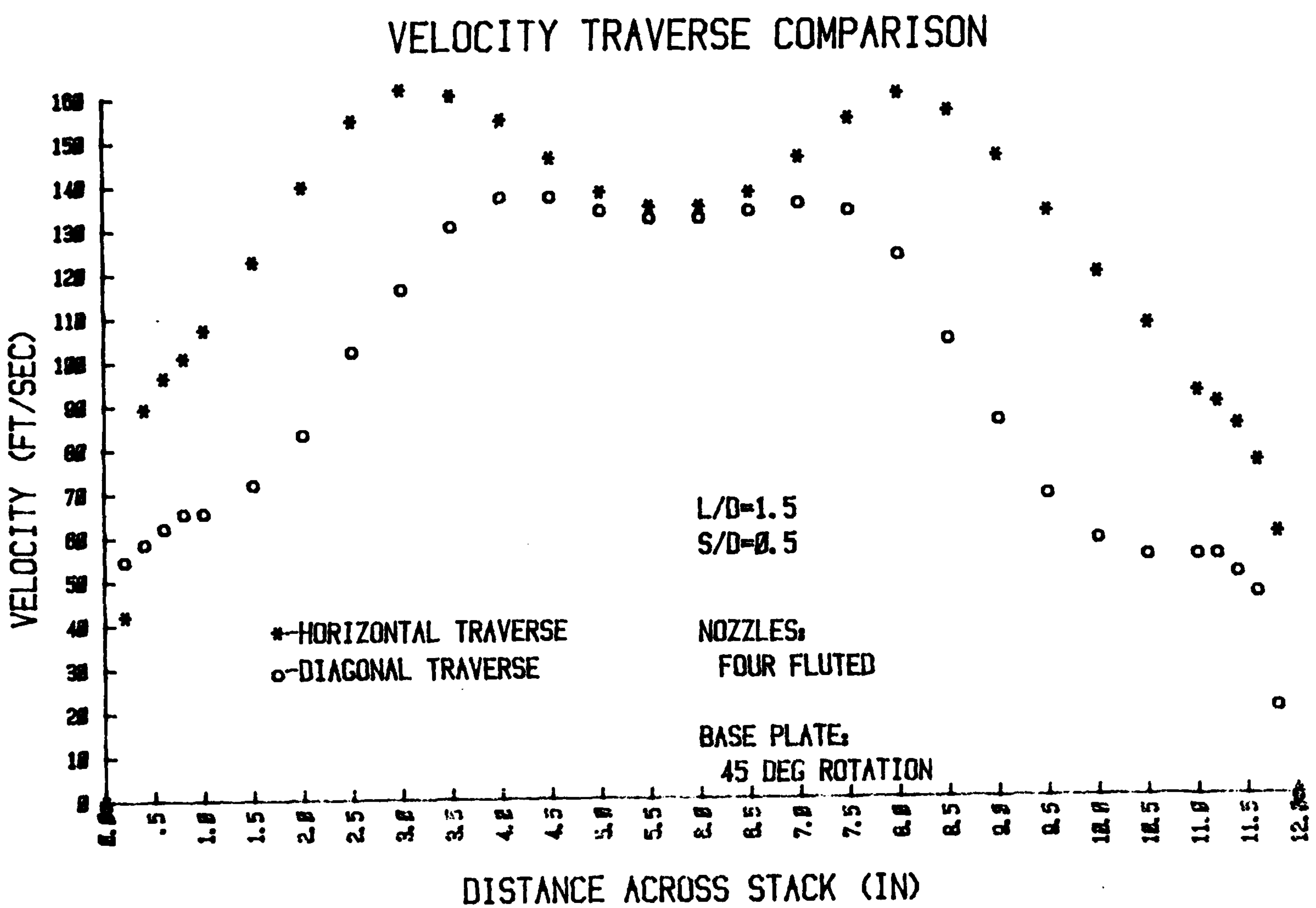


Figure 30. (contd) VTD Comparison: 45^{o} Rotation

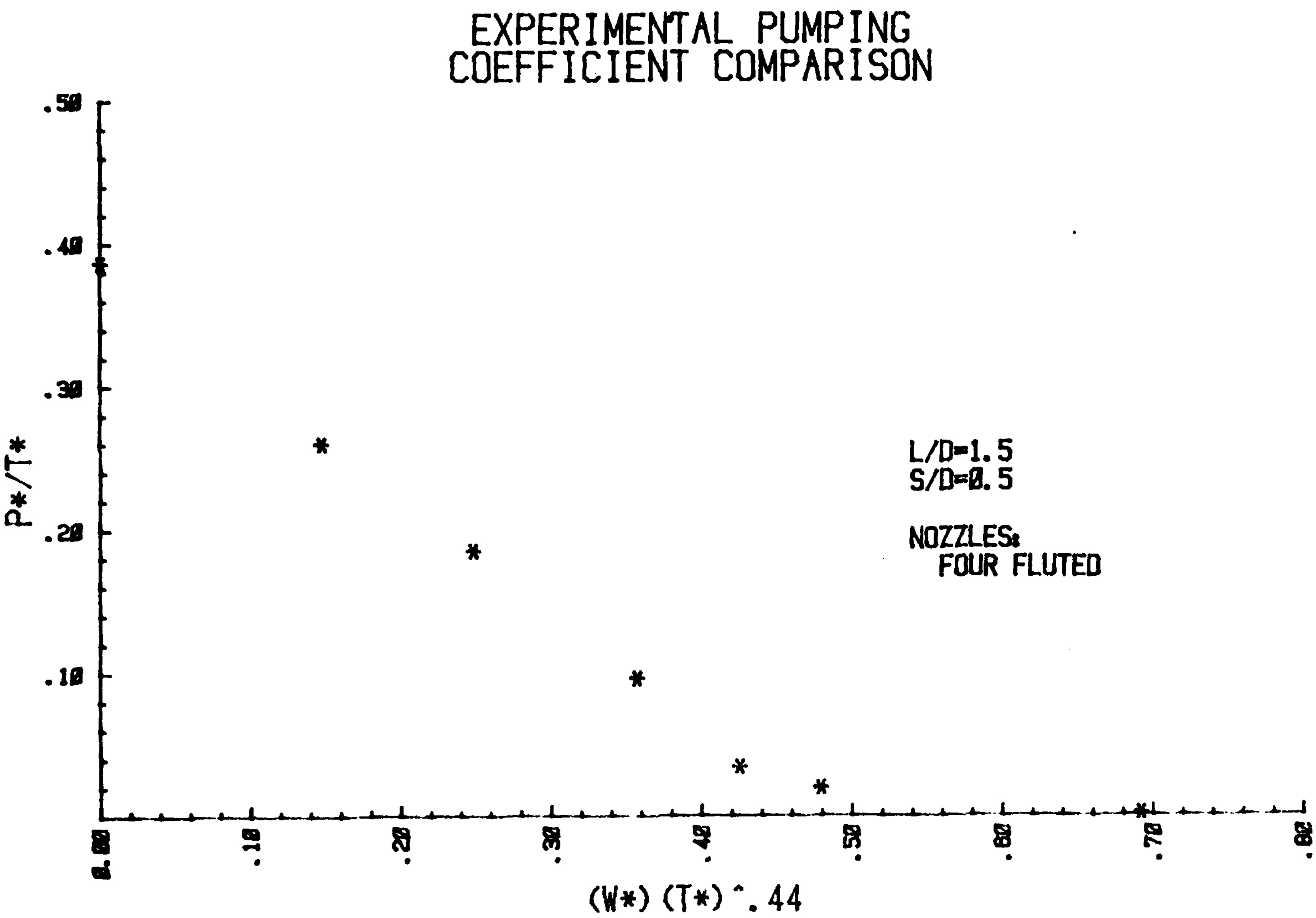


Figure 31. S/D = 0.50

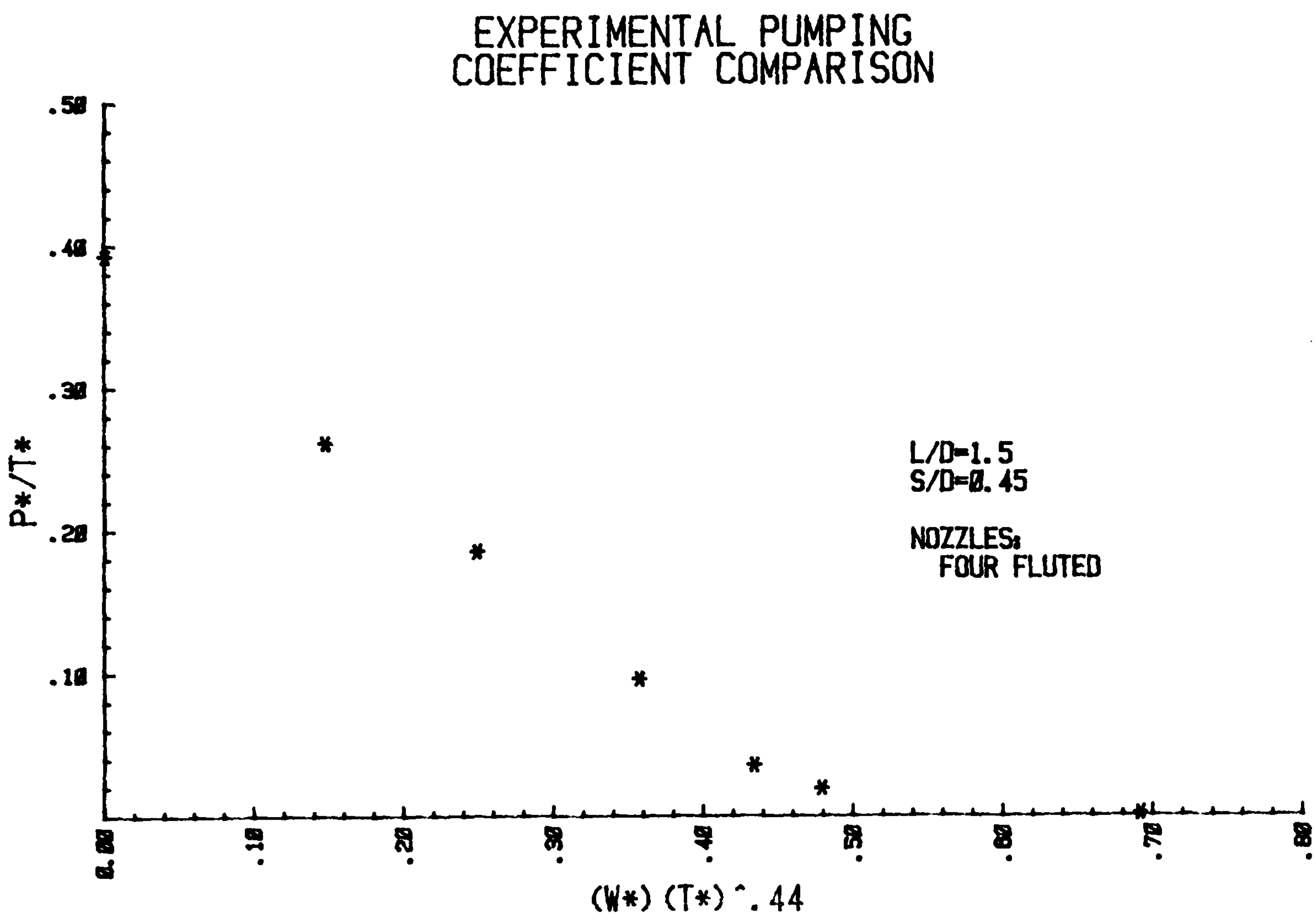


Figure 32. S/D = 0.45

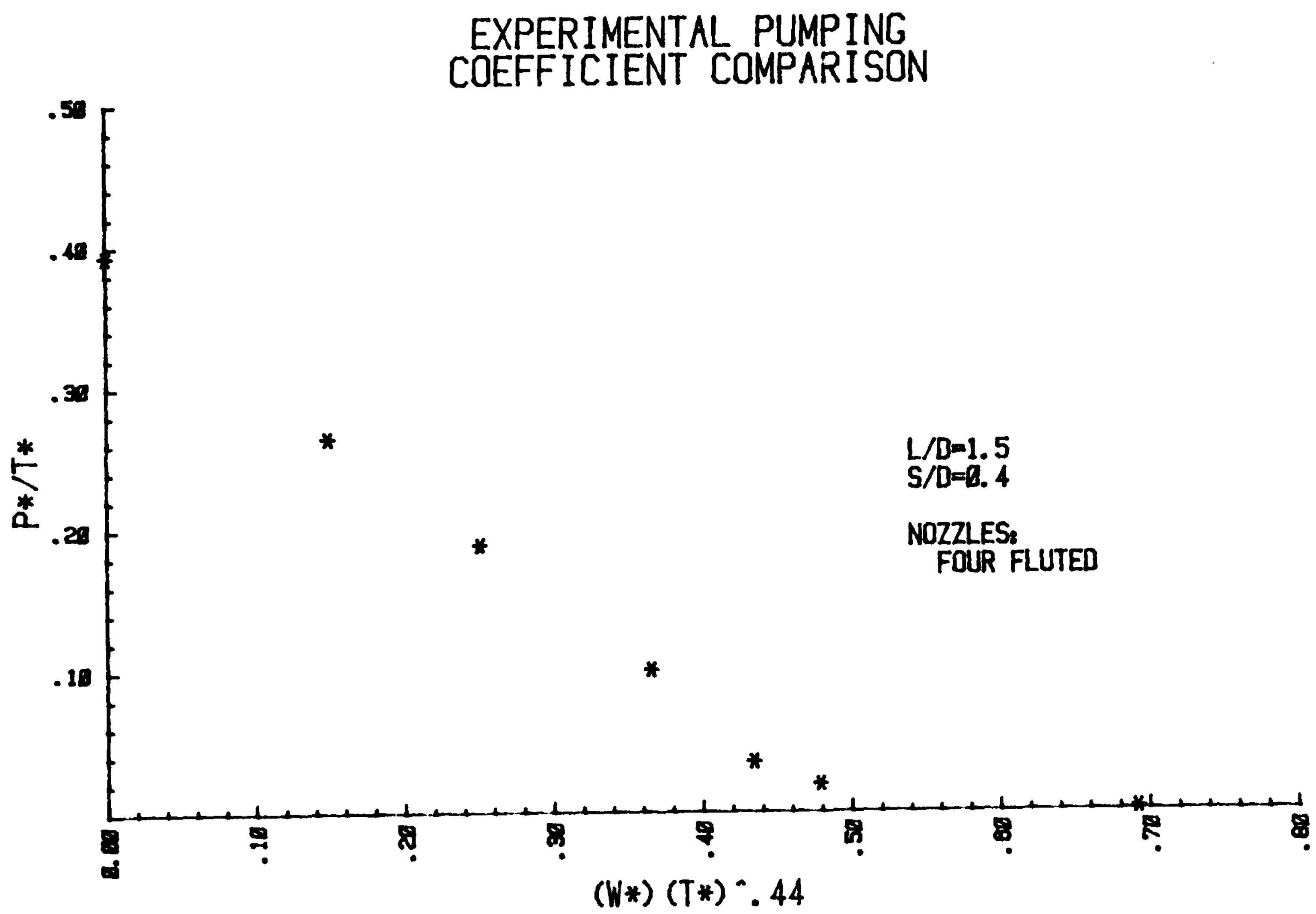


Figure 33. S/D = 0.40

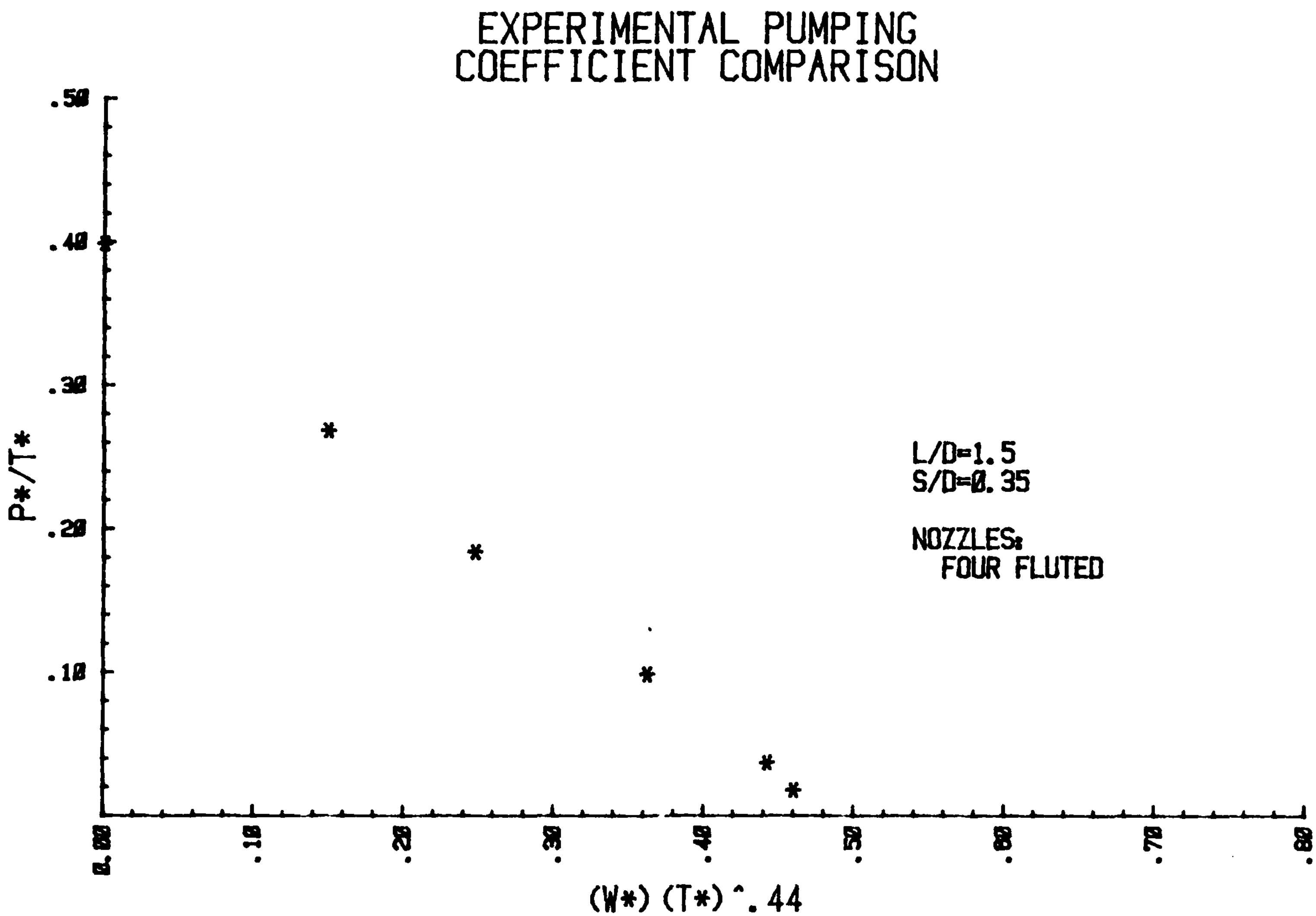


Figure 34. S/D = 0.35

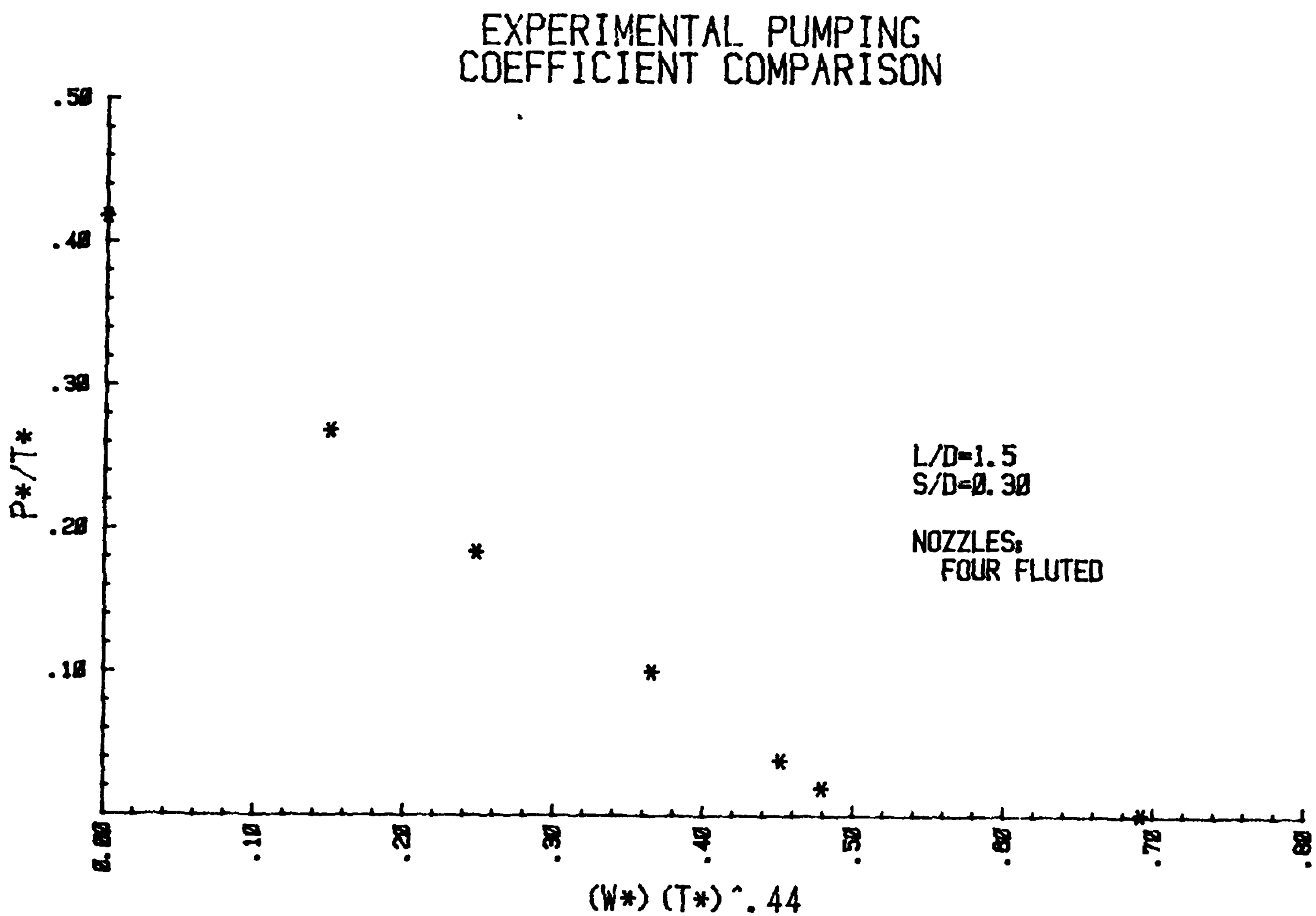


Figure 35. S/D = 0.30

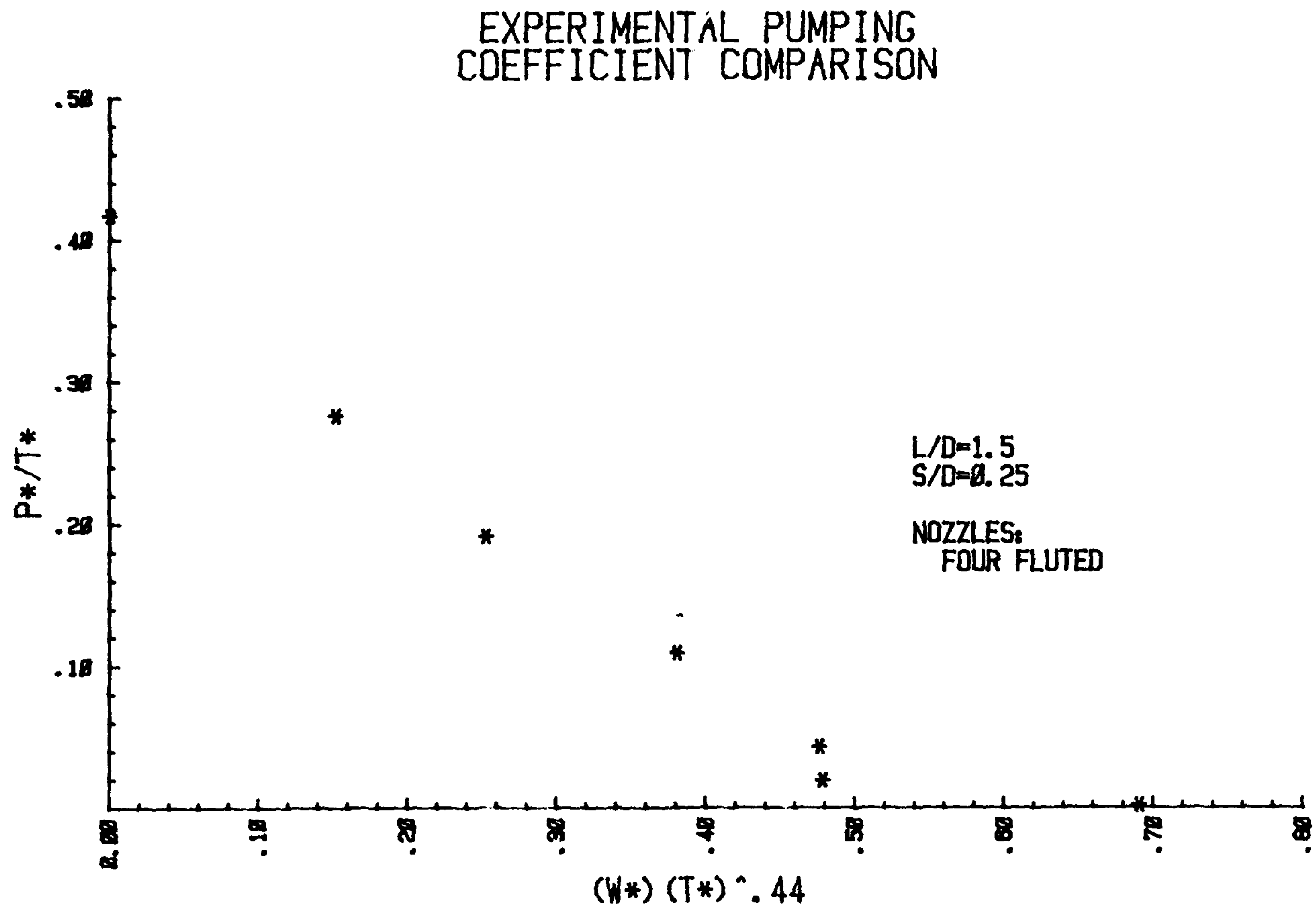


Figure 36. S/D = 0.25

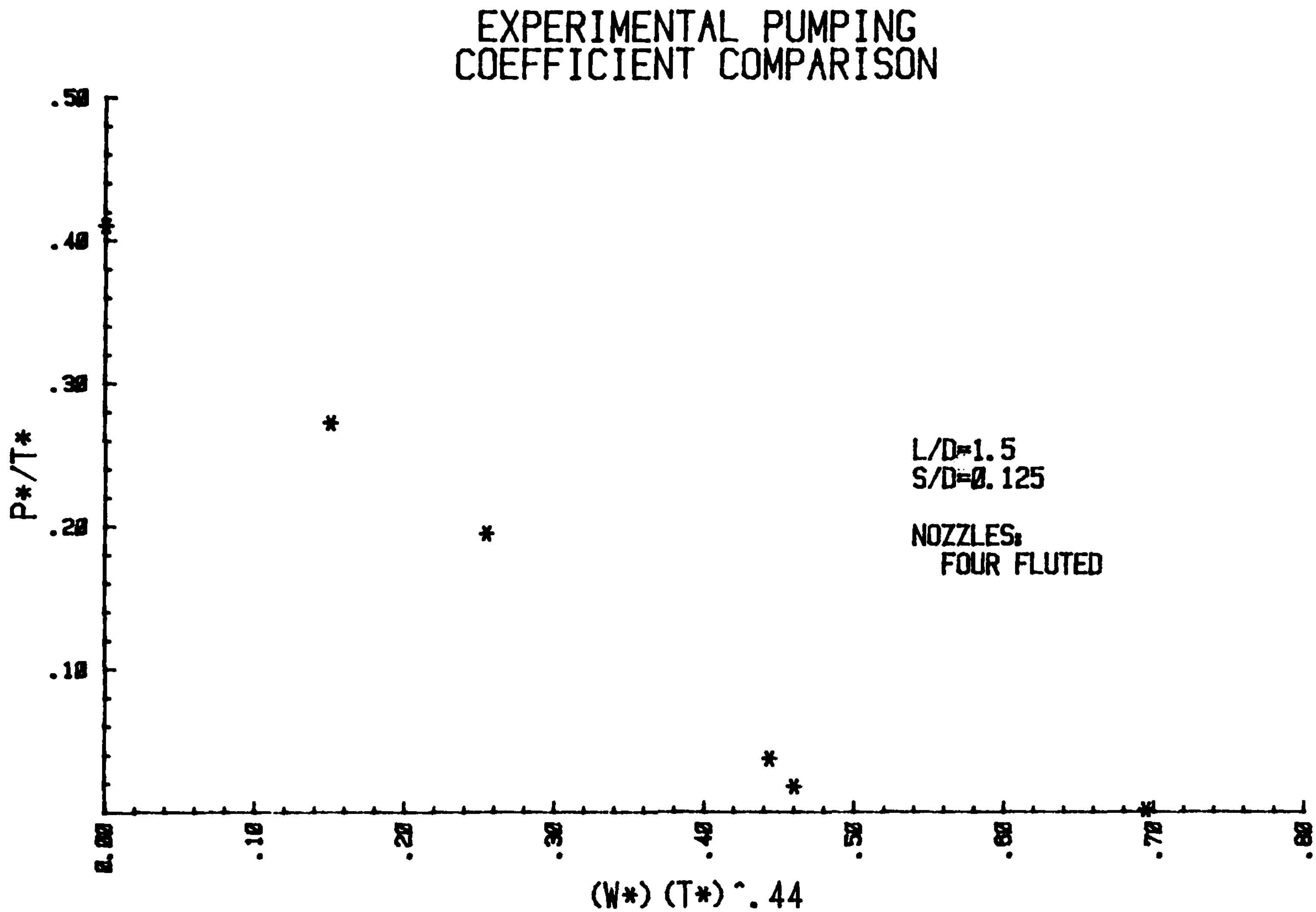


Figure 37. S/D = 0.125

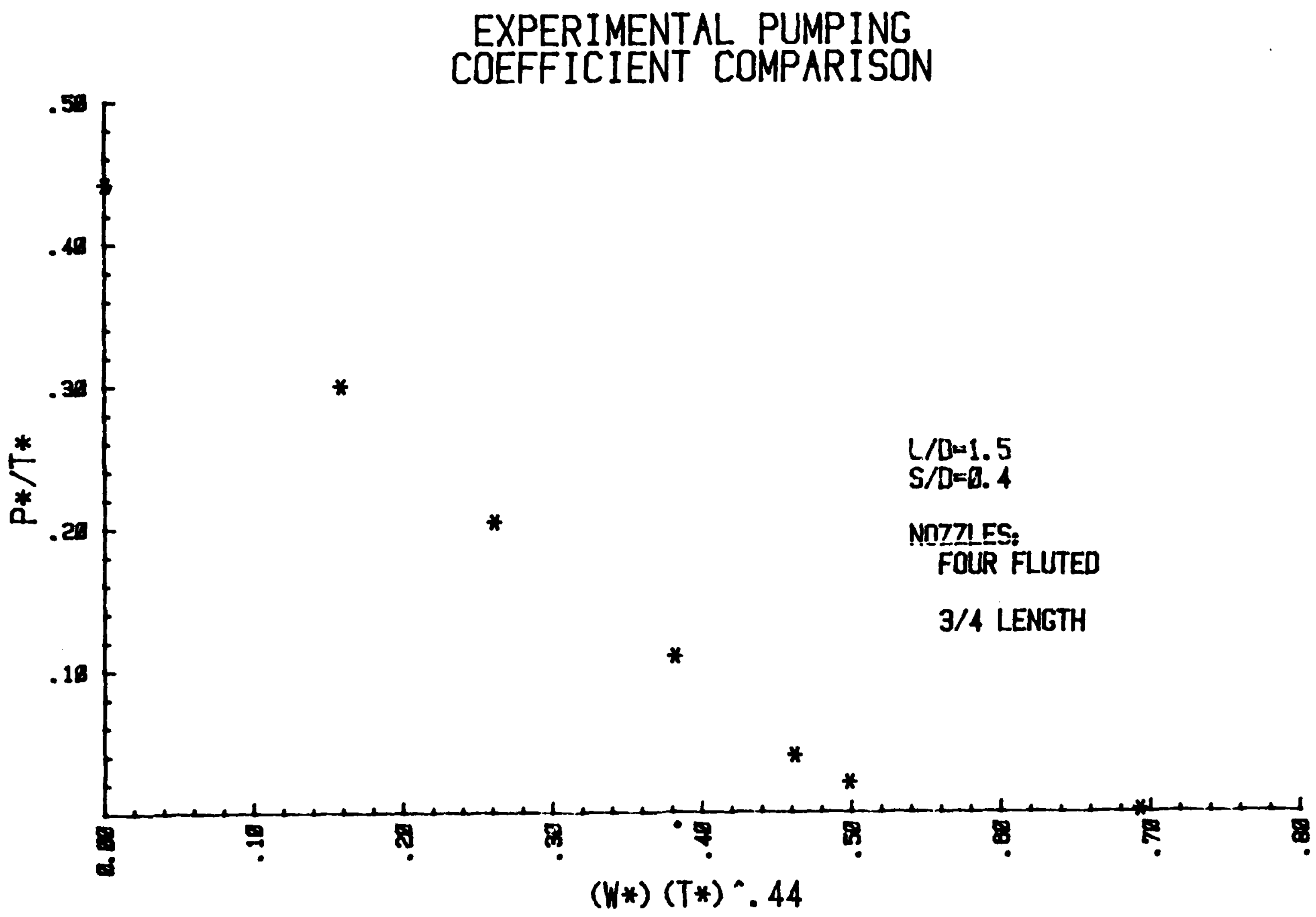


Figure 38. 3/4 Length Fluted Nozzles PCD

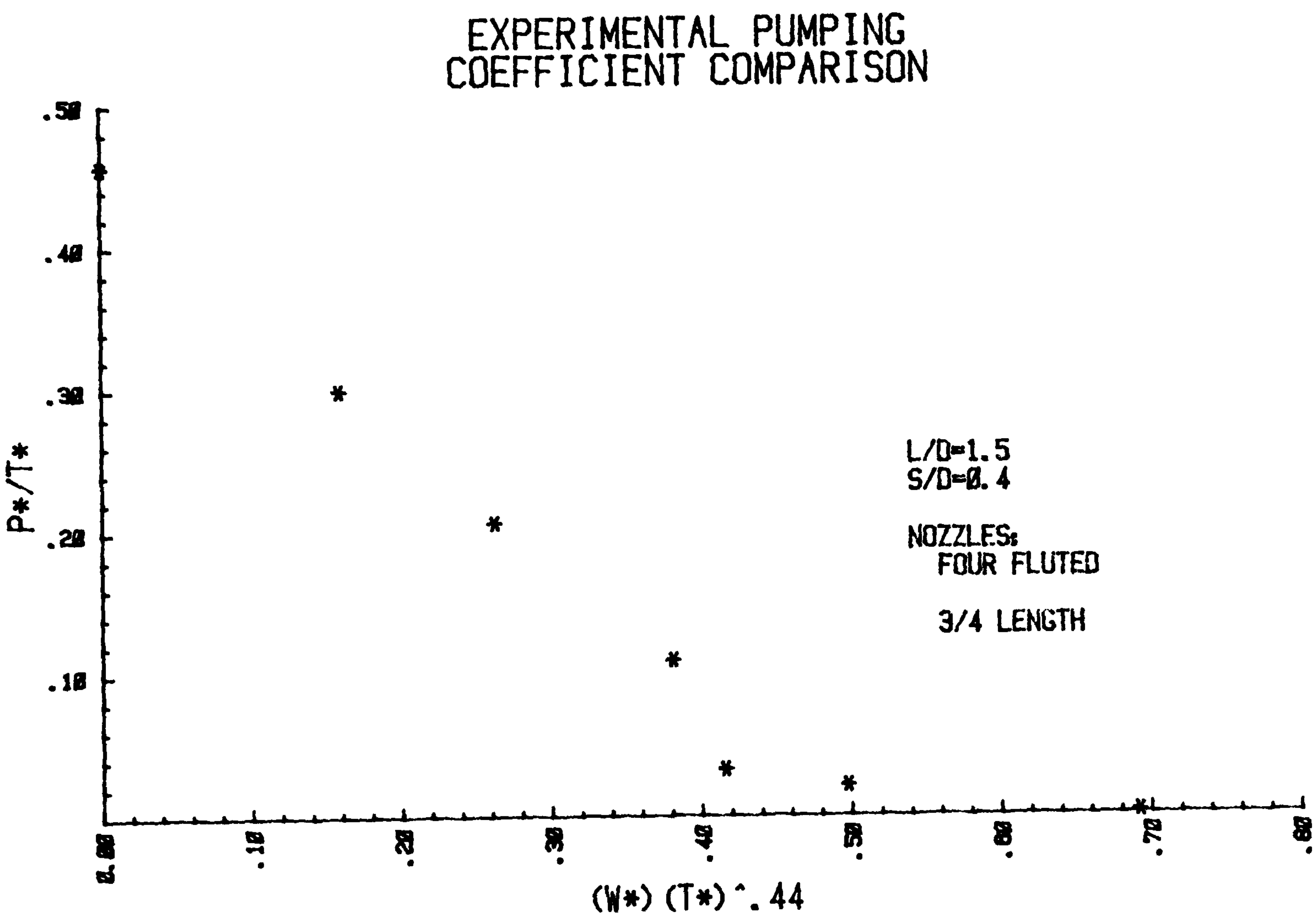


Figure 39. 3/4 Length Fluted Nozzles (Full Run)

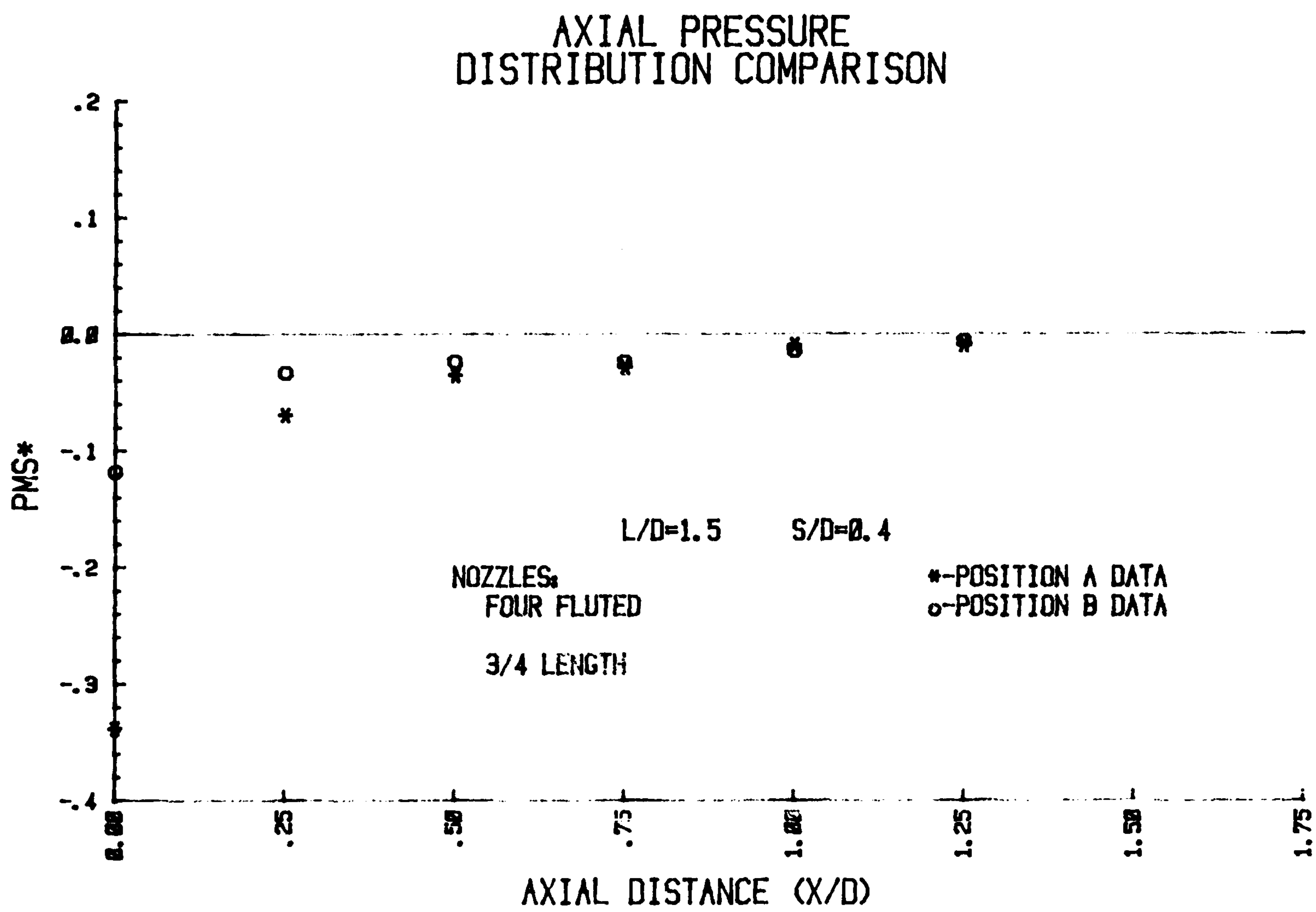


Figure 39. (contd) MSD

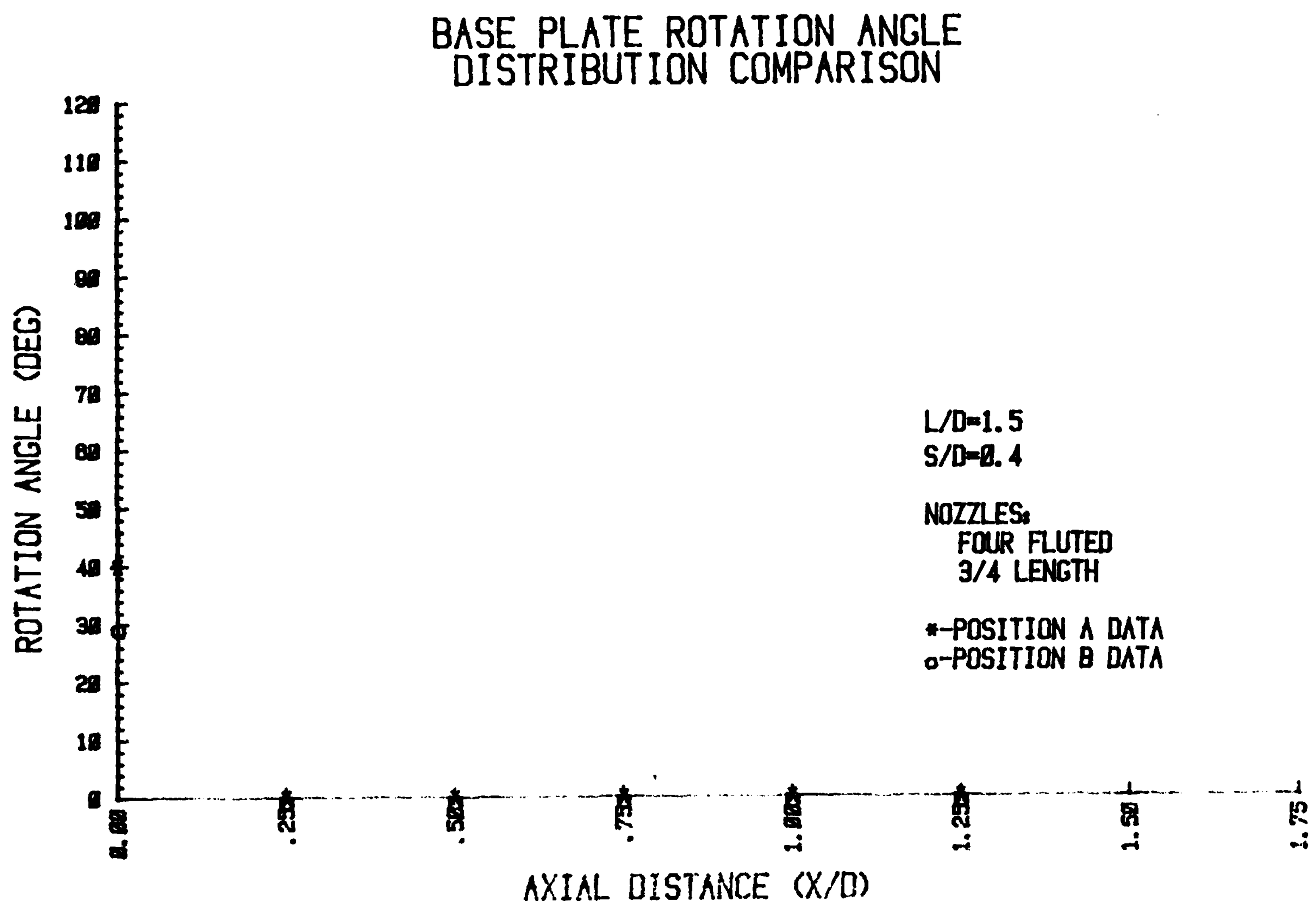


Figure 39. (contd) MSD

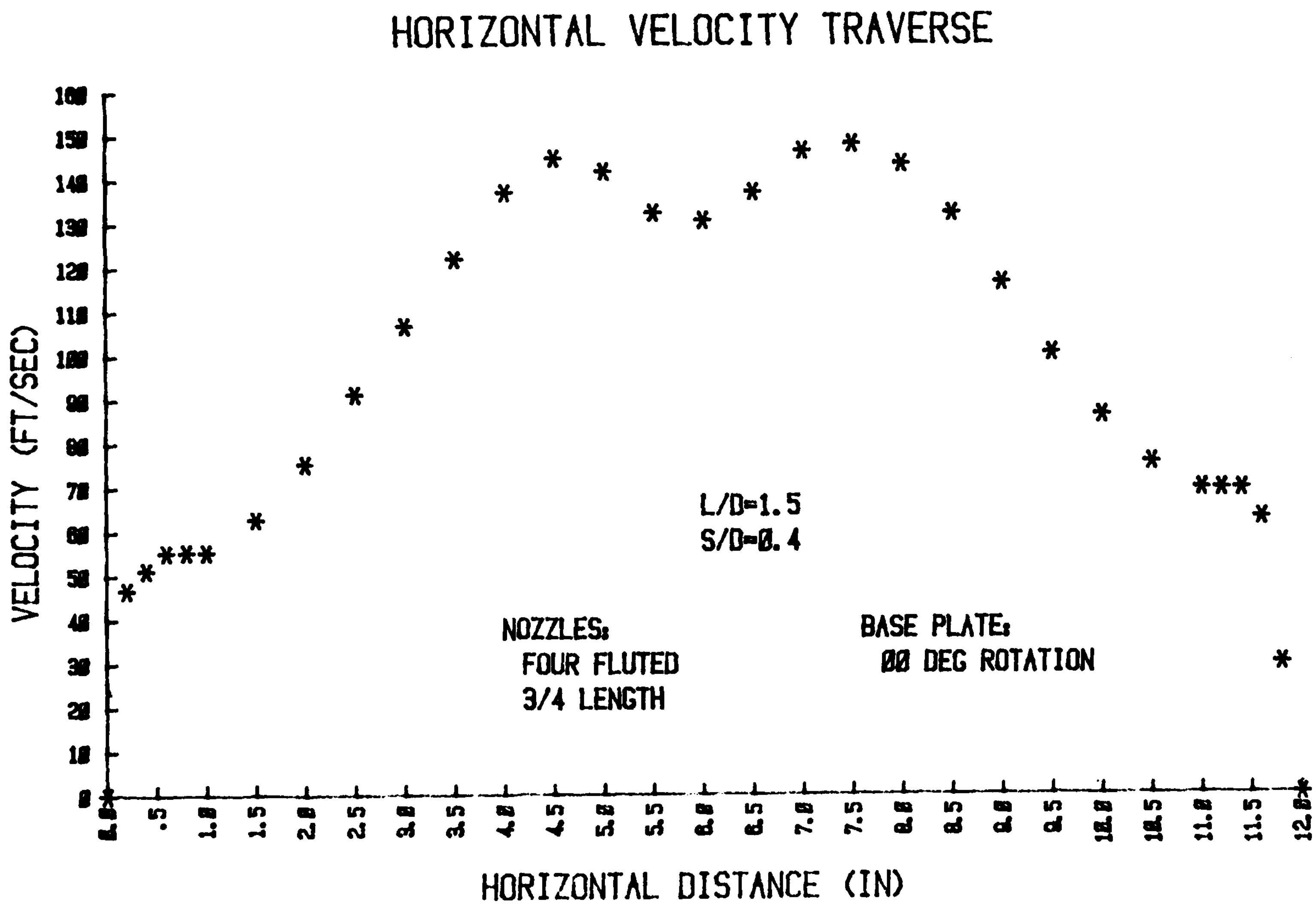


Figure 39. (contd) VTD

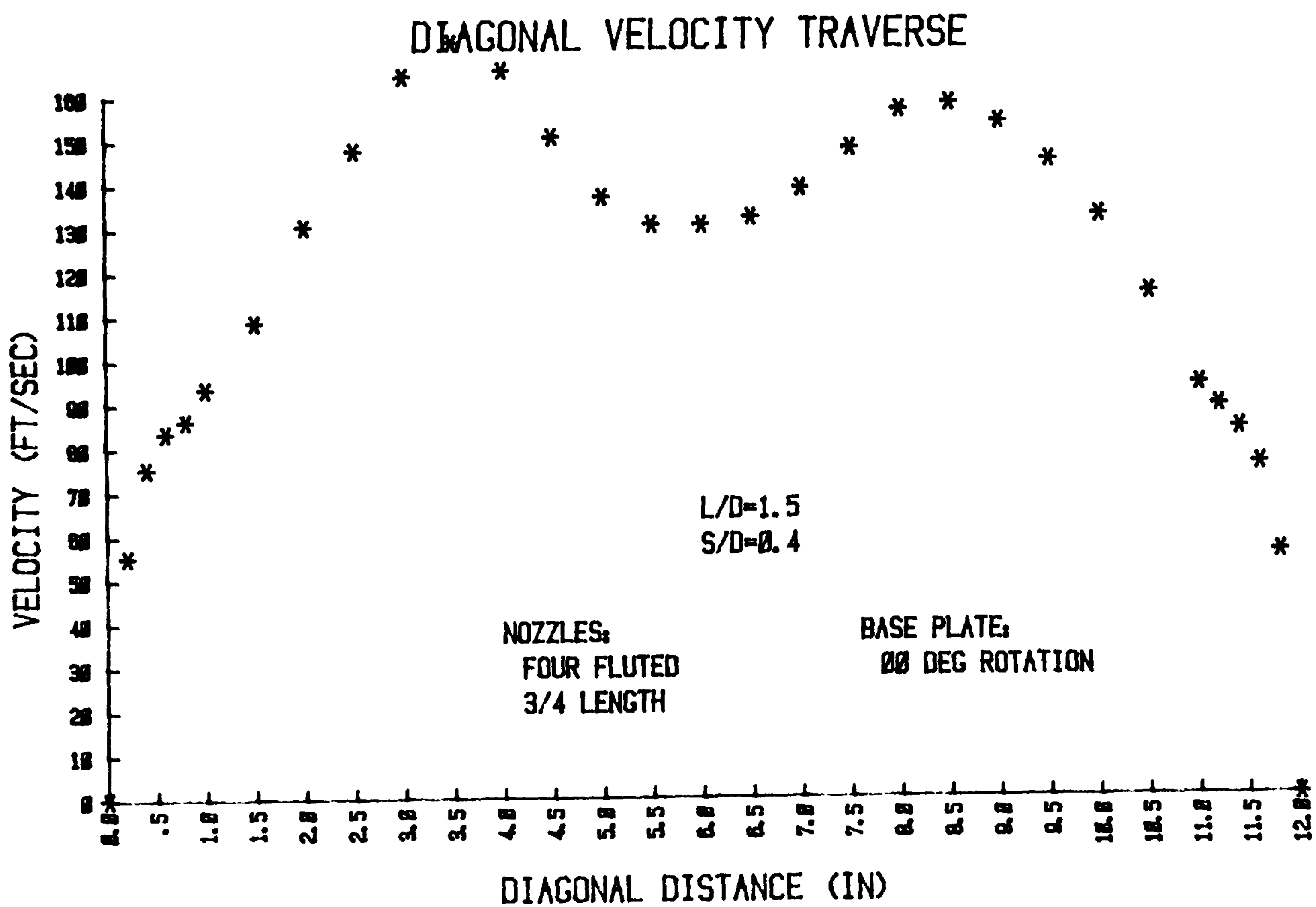


Figure 39. (contd) VTD

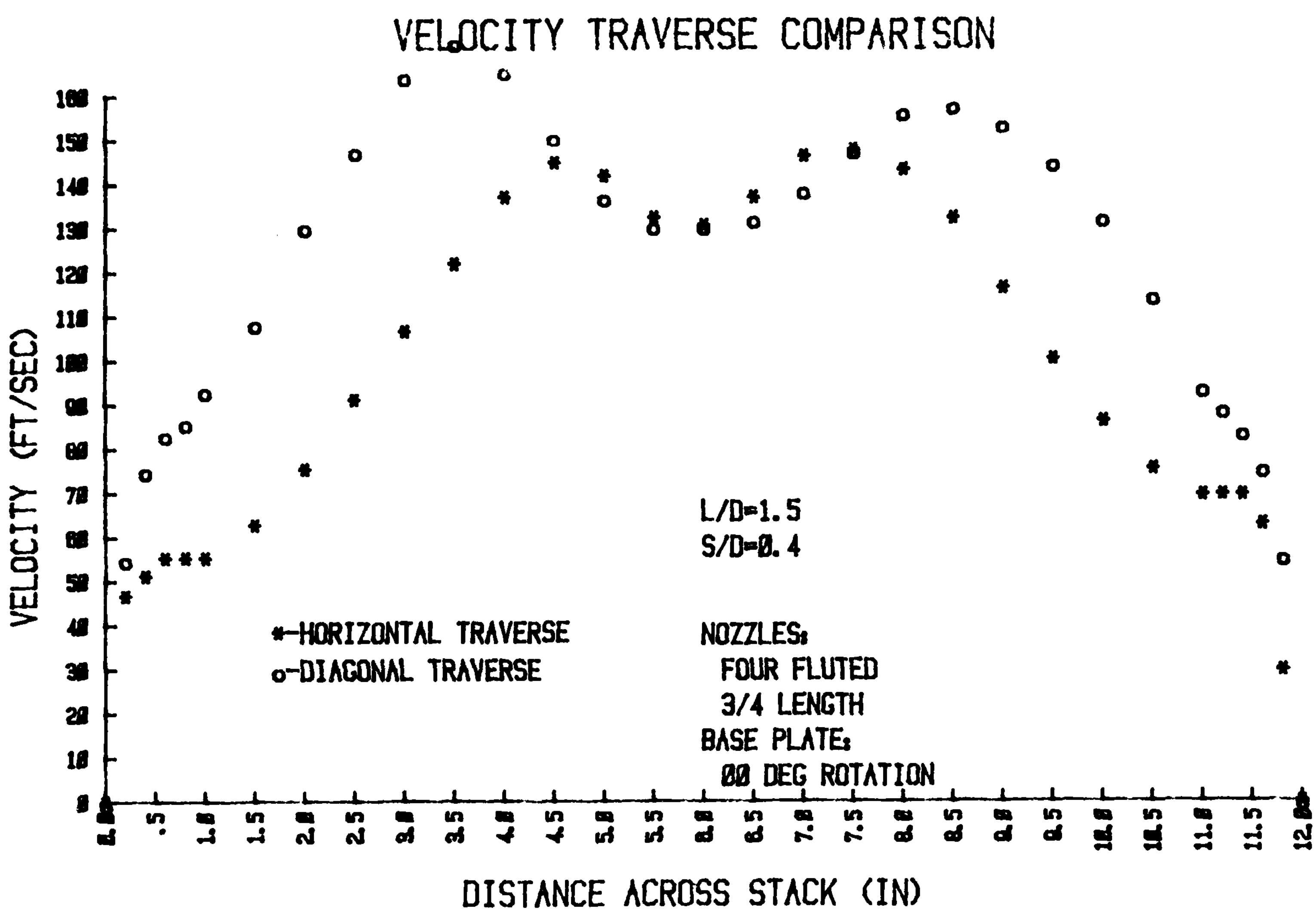


Figure 39. (contd) VTD Comparison

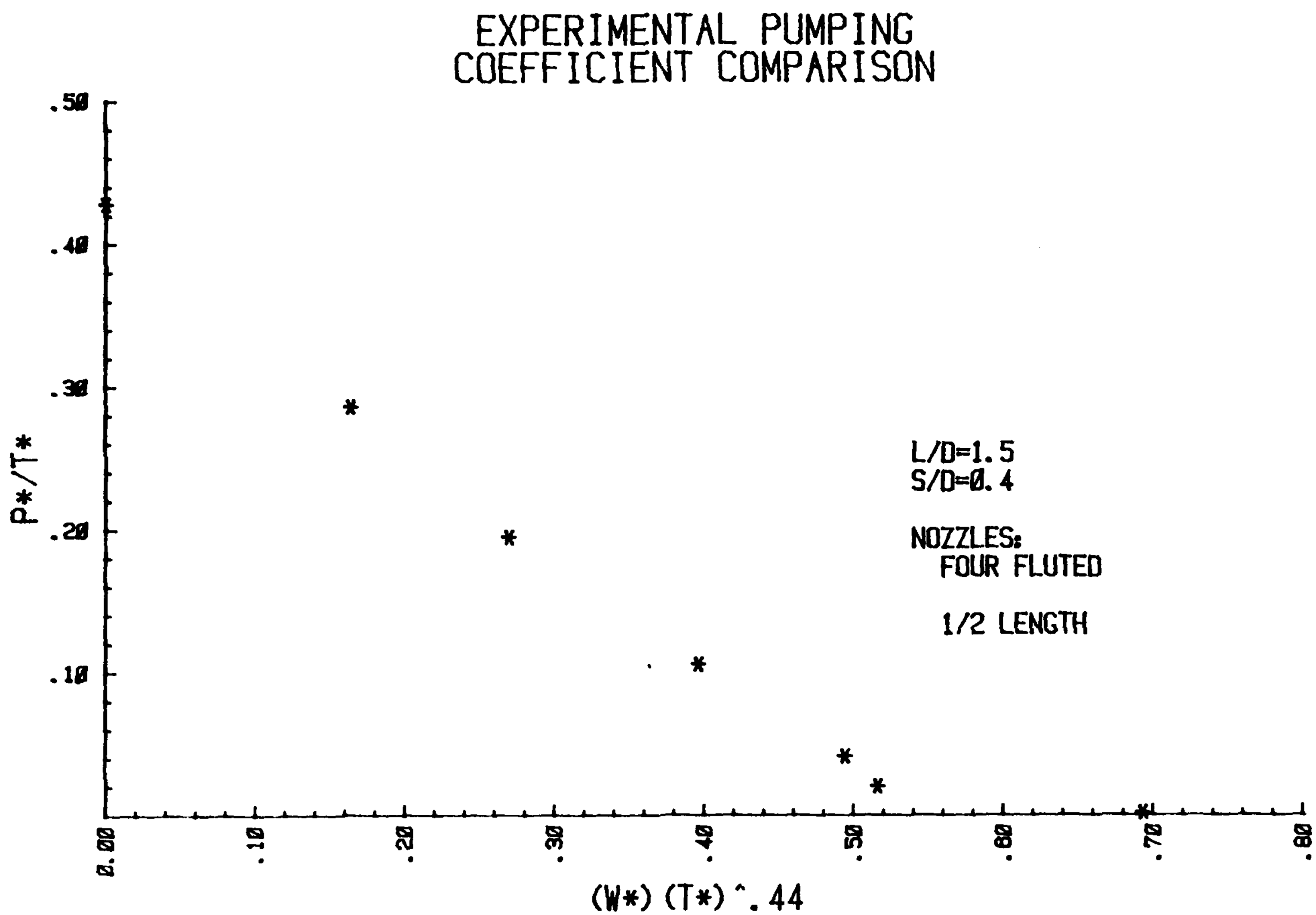


Figure 40. 1/2 Length Fluted Nozzles (Full Run)

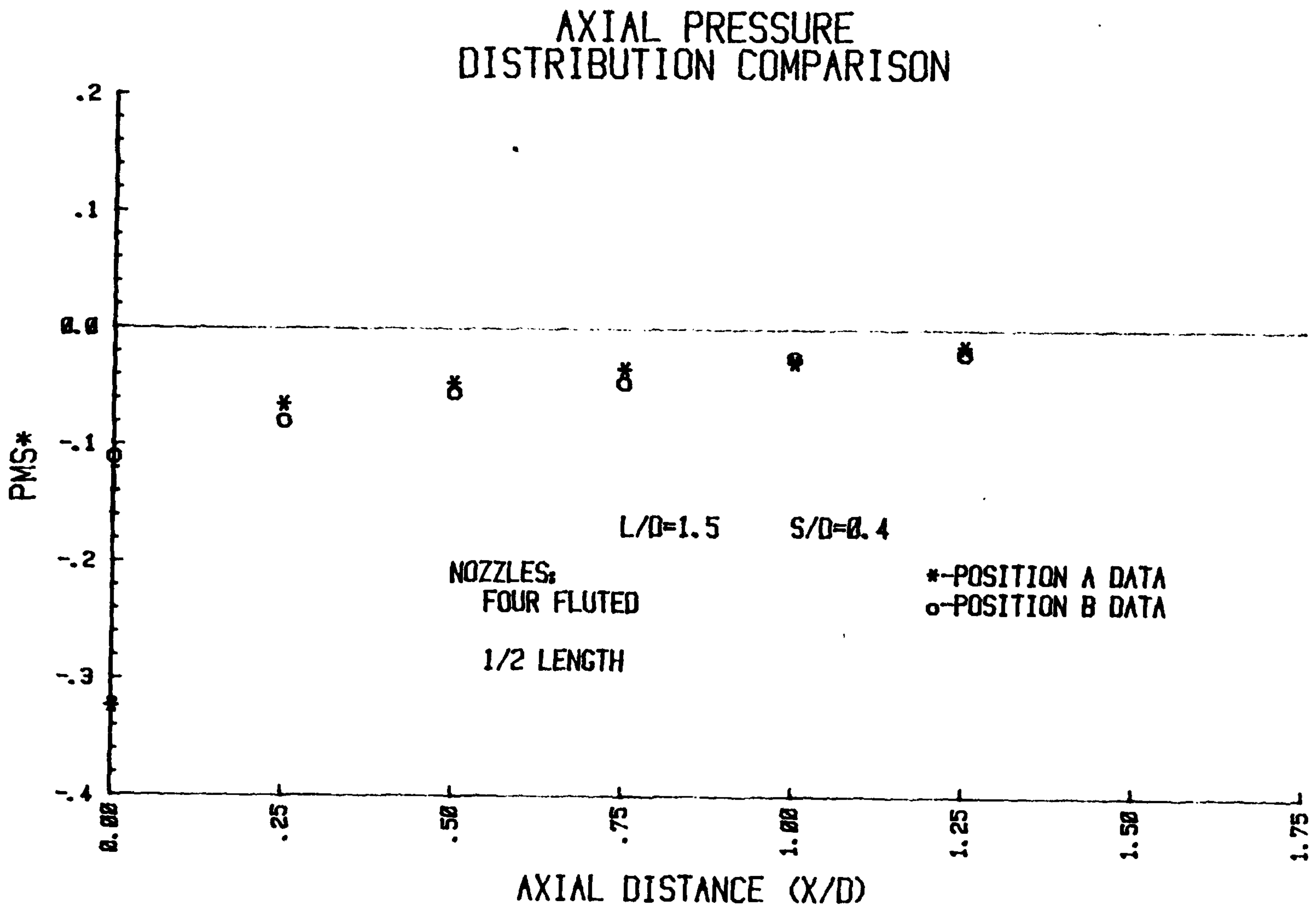


Figure 40. (contd) MSD

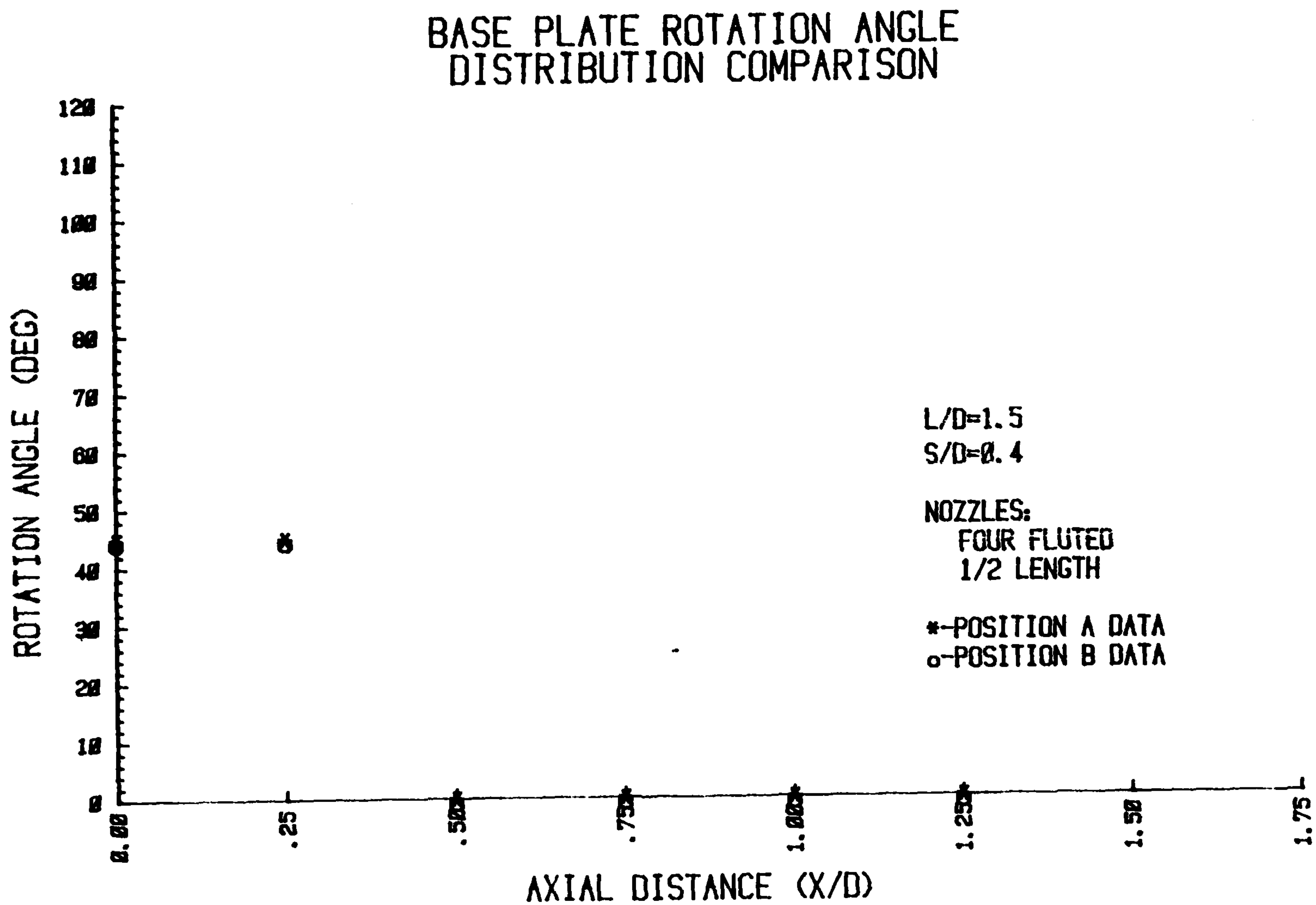


Figure 40. (contd) MSD

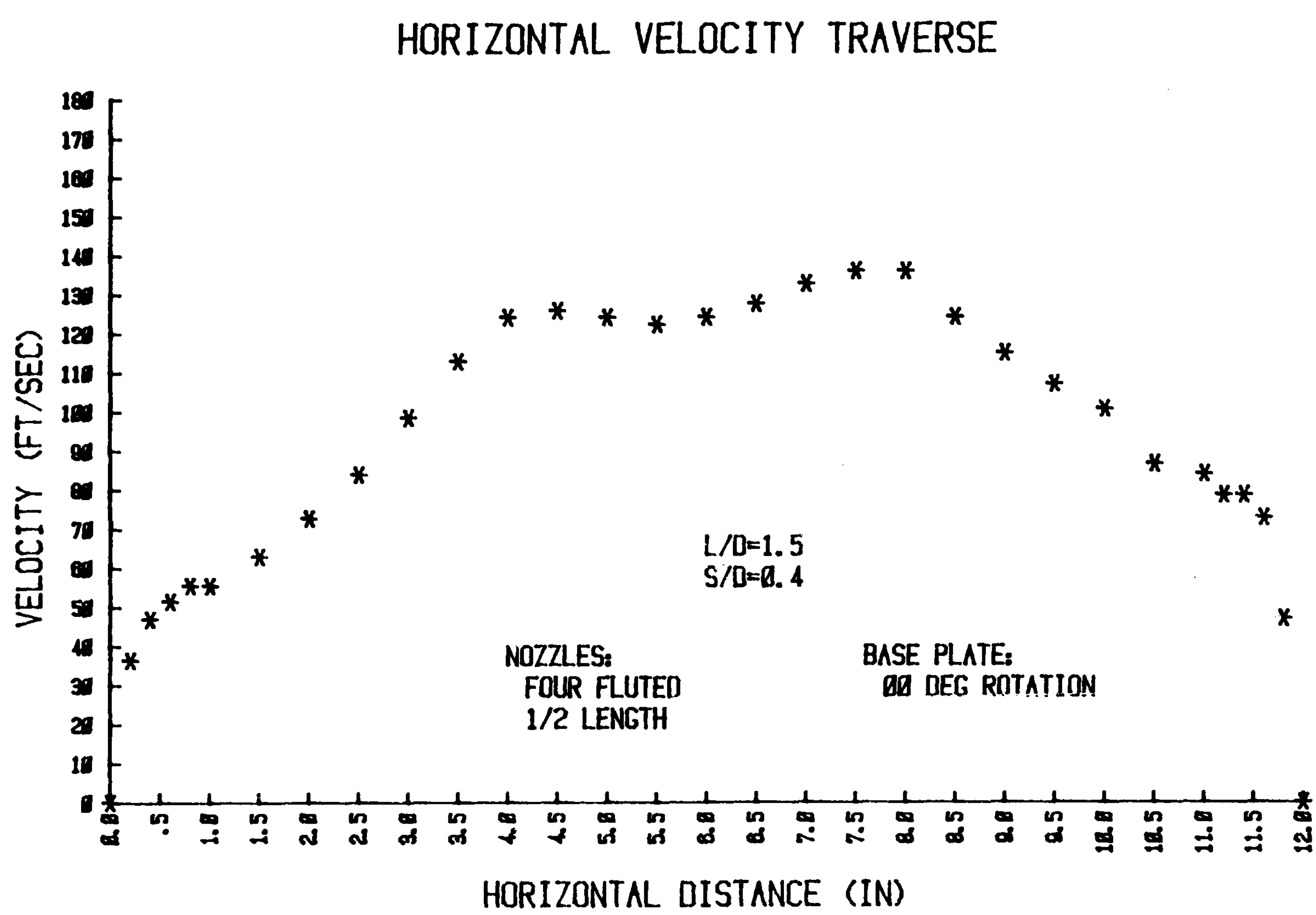


Figure 40. (contd) VTD

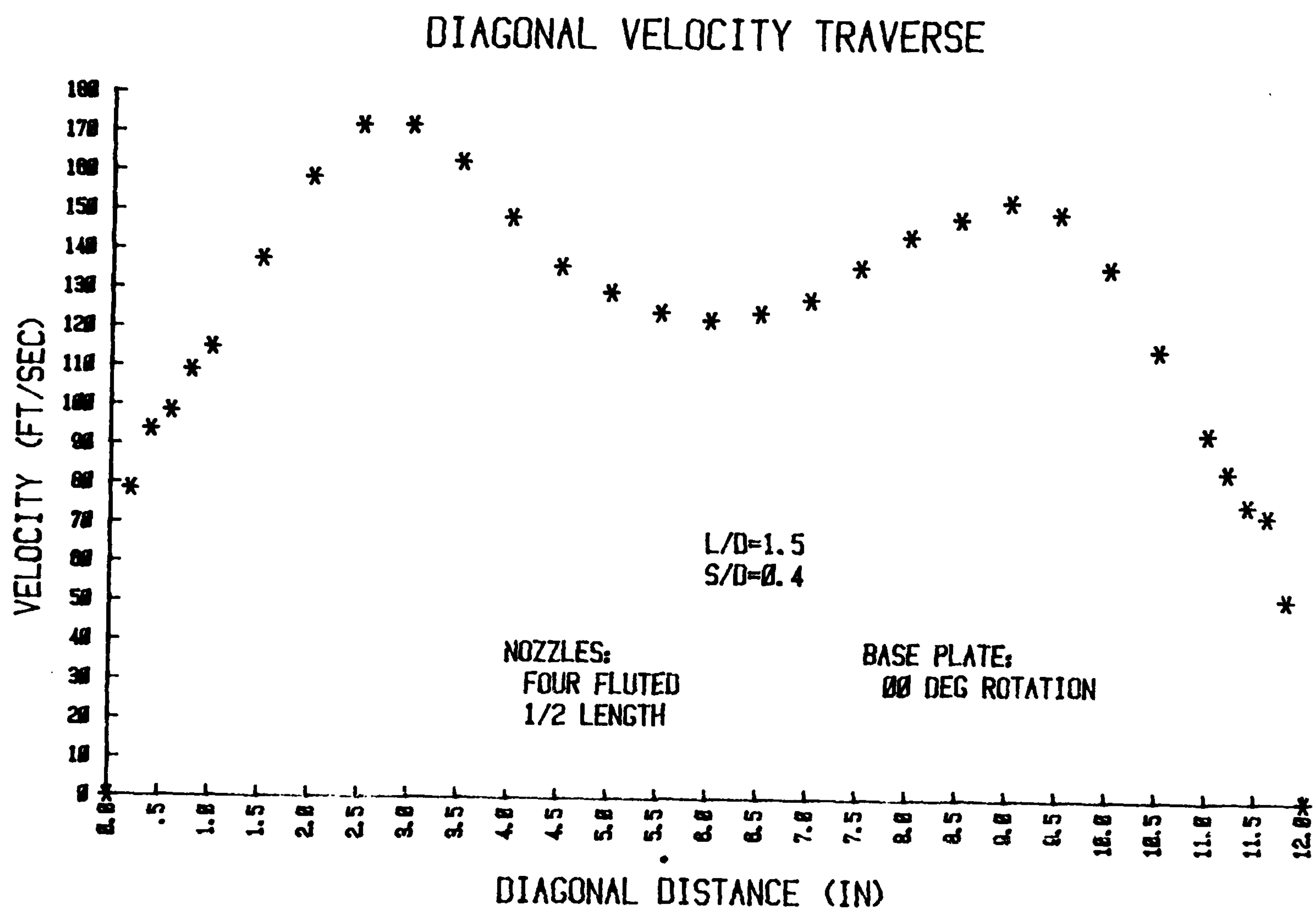


Figure 40. (contd) VTD

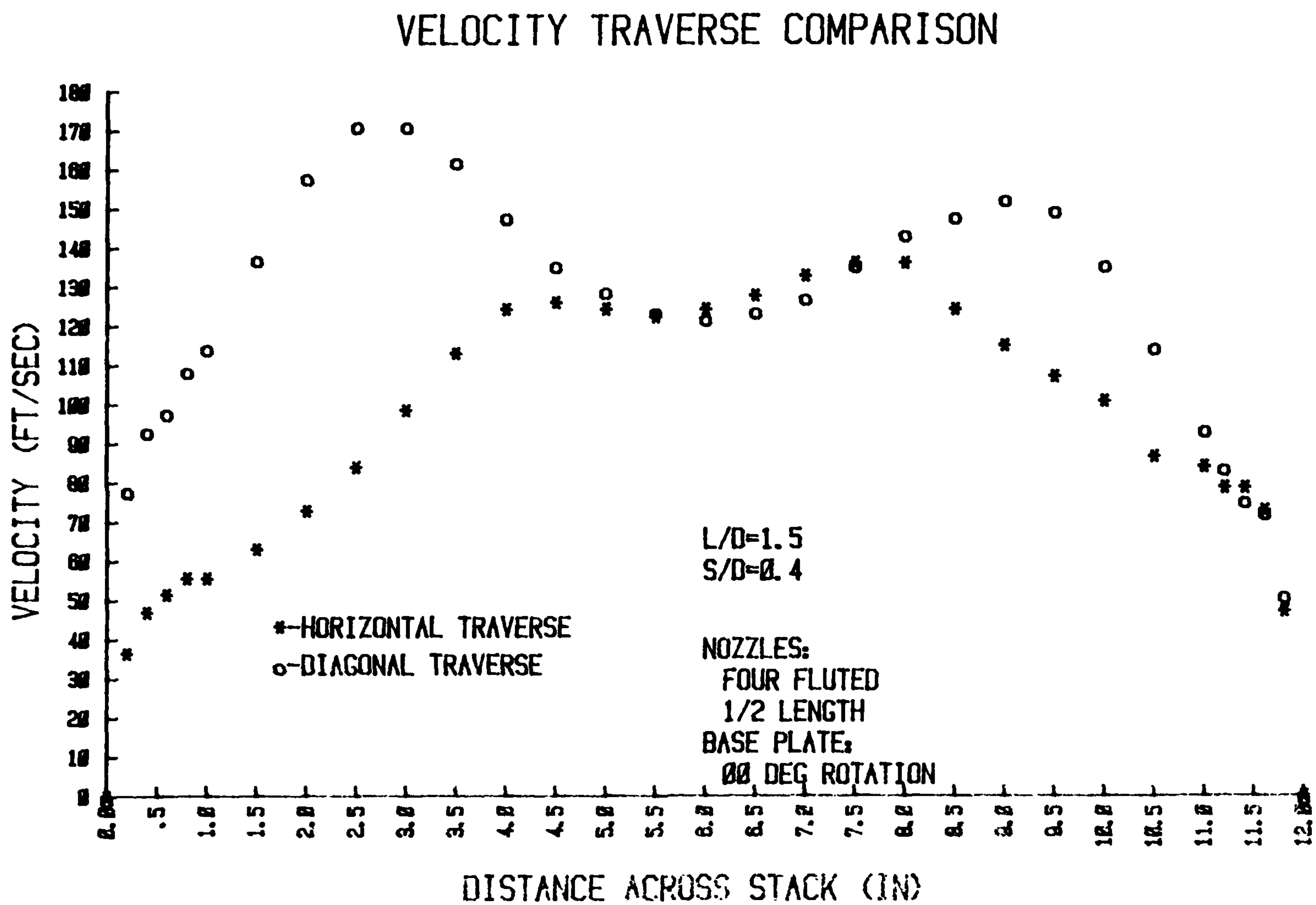


Figure 40. (contd) VTD Comparison

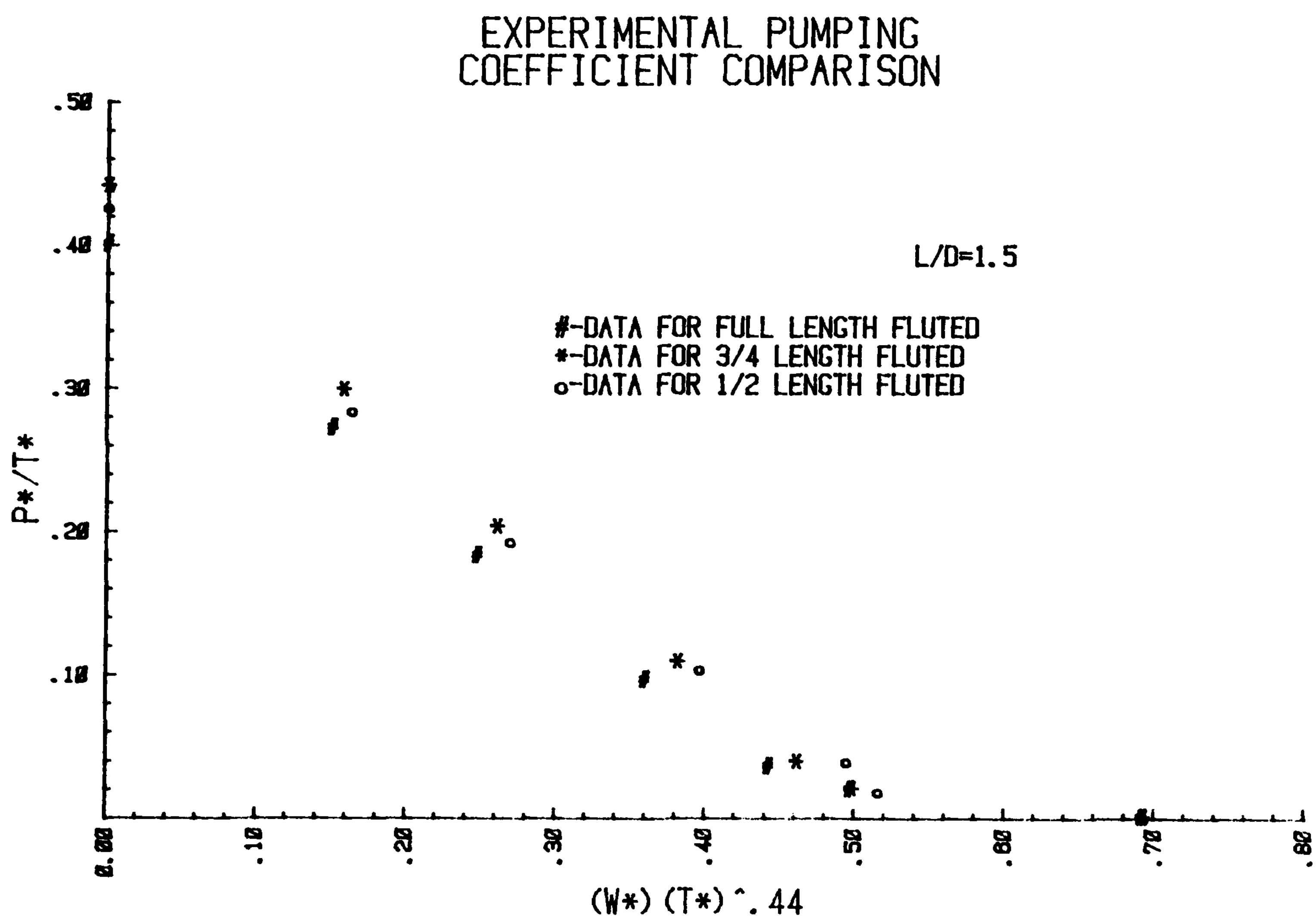


Figure 41. PCD Comparison

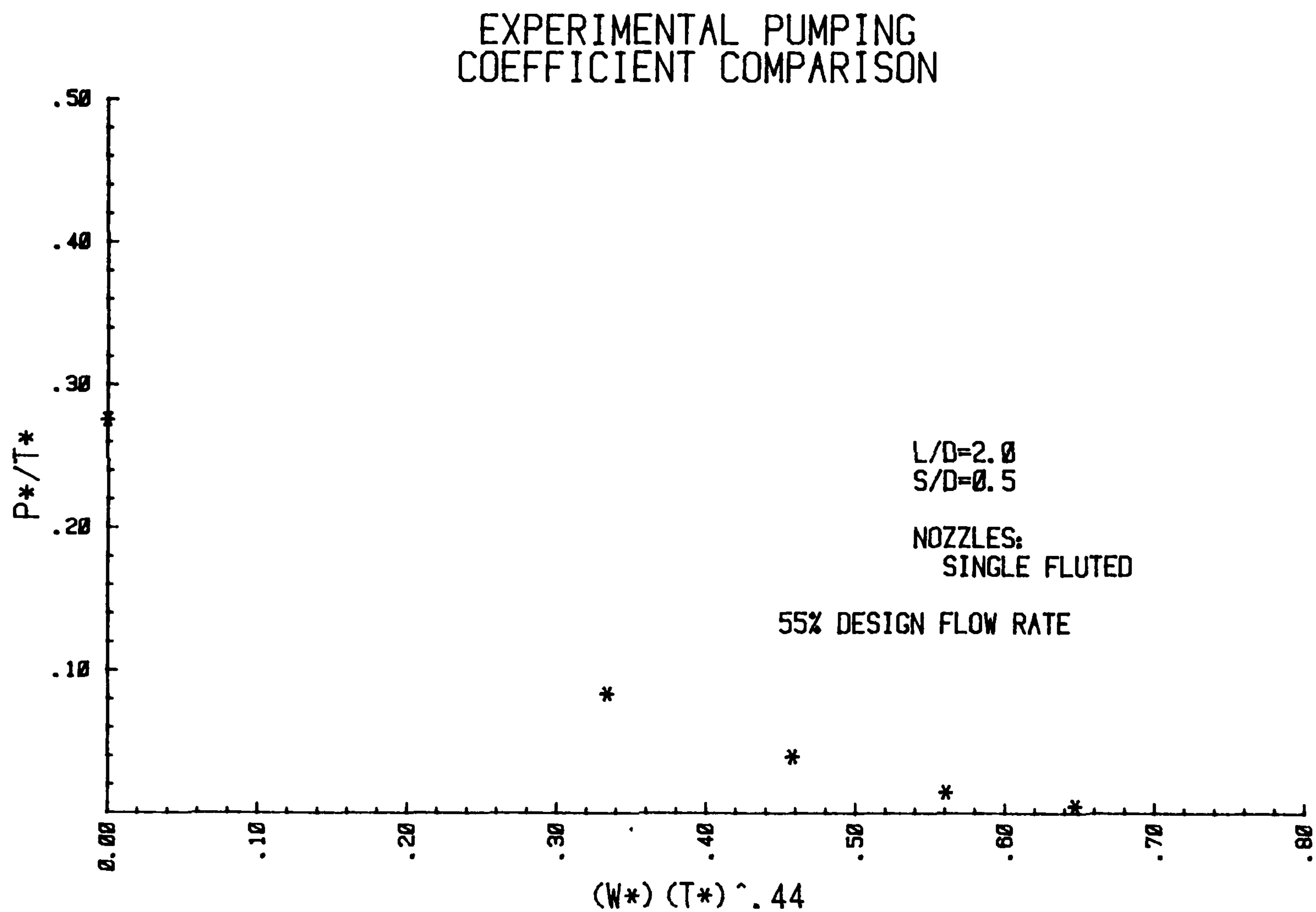


Figure 42. 55 Percent Design Flow Rate

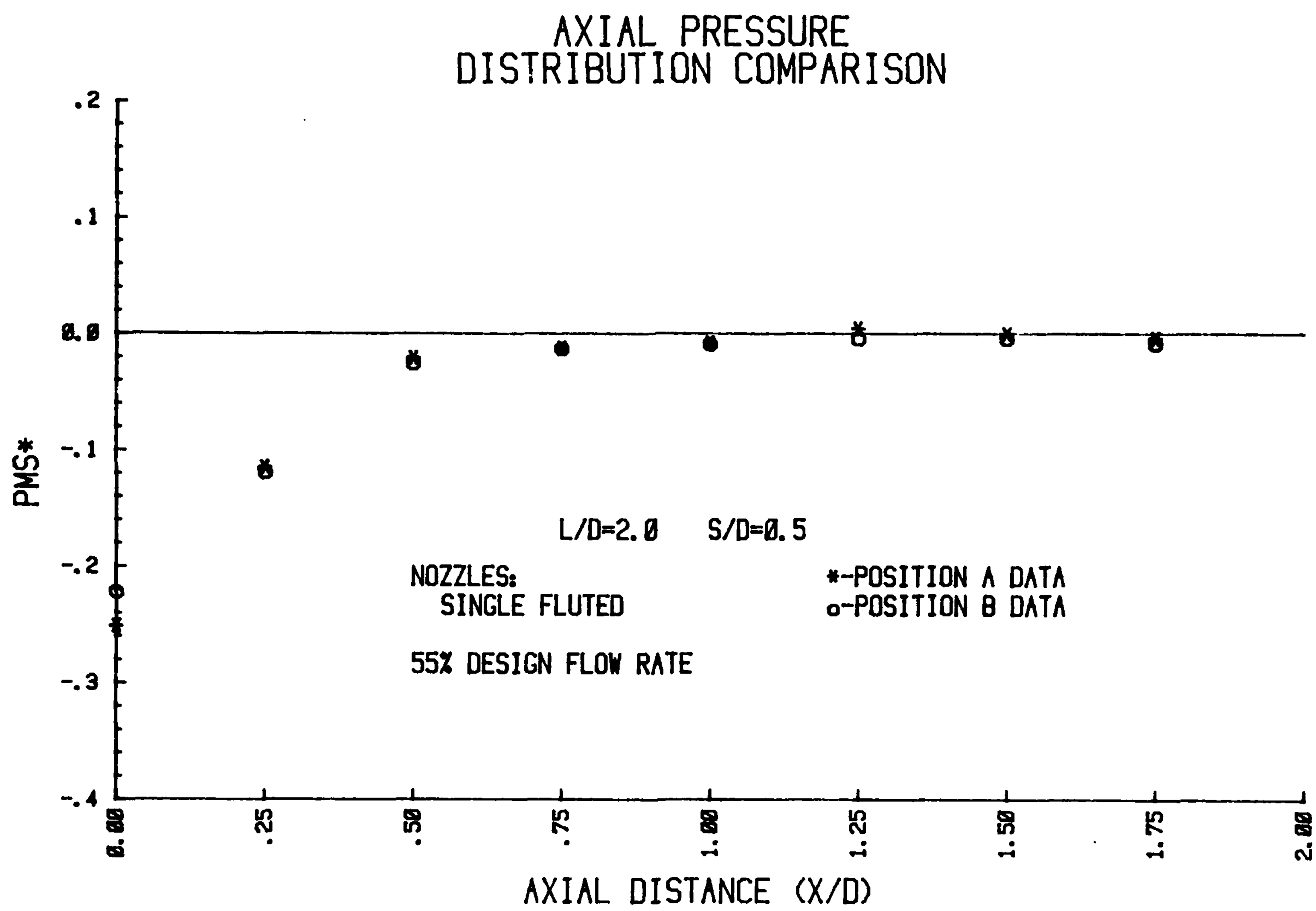


Figure 42. (contd) MSD

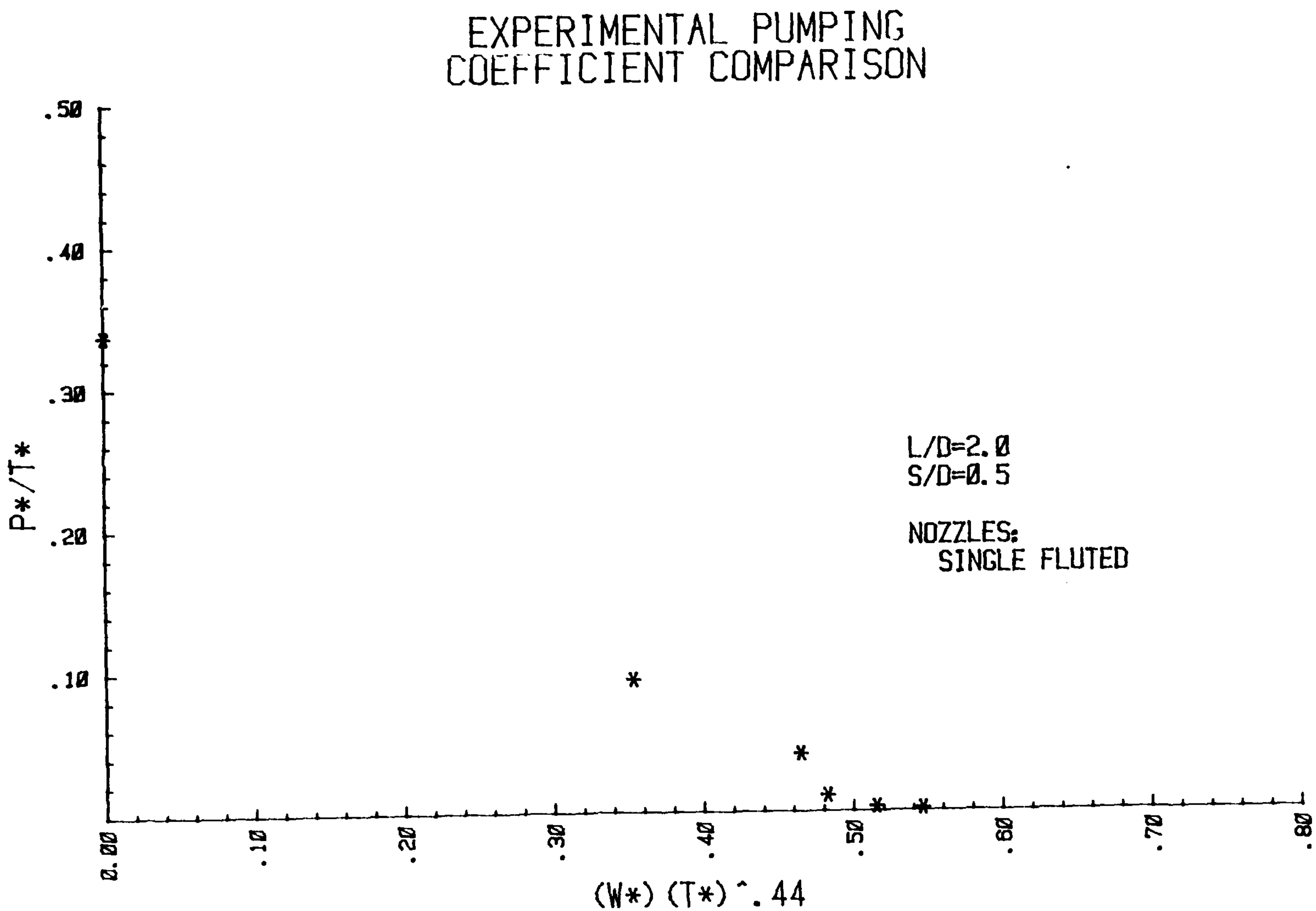


Figure 43. 100 Percent Design Flow Rate

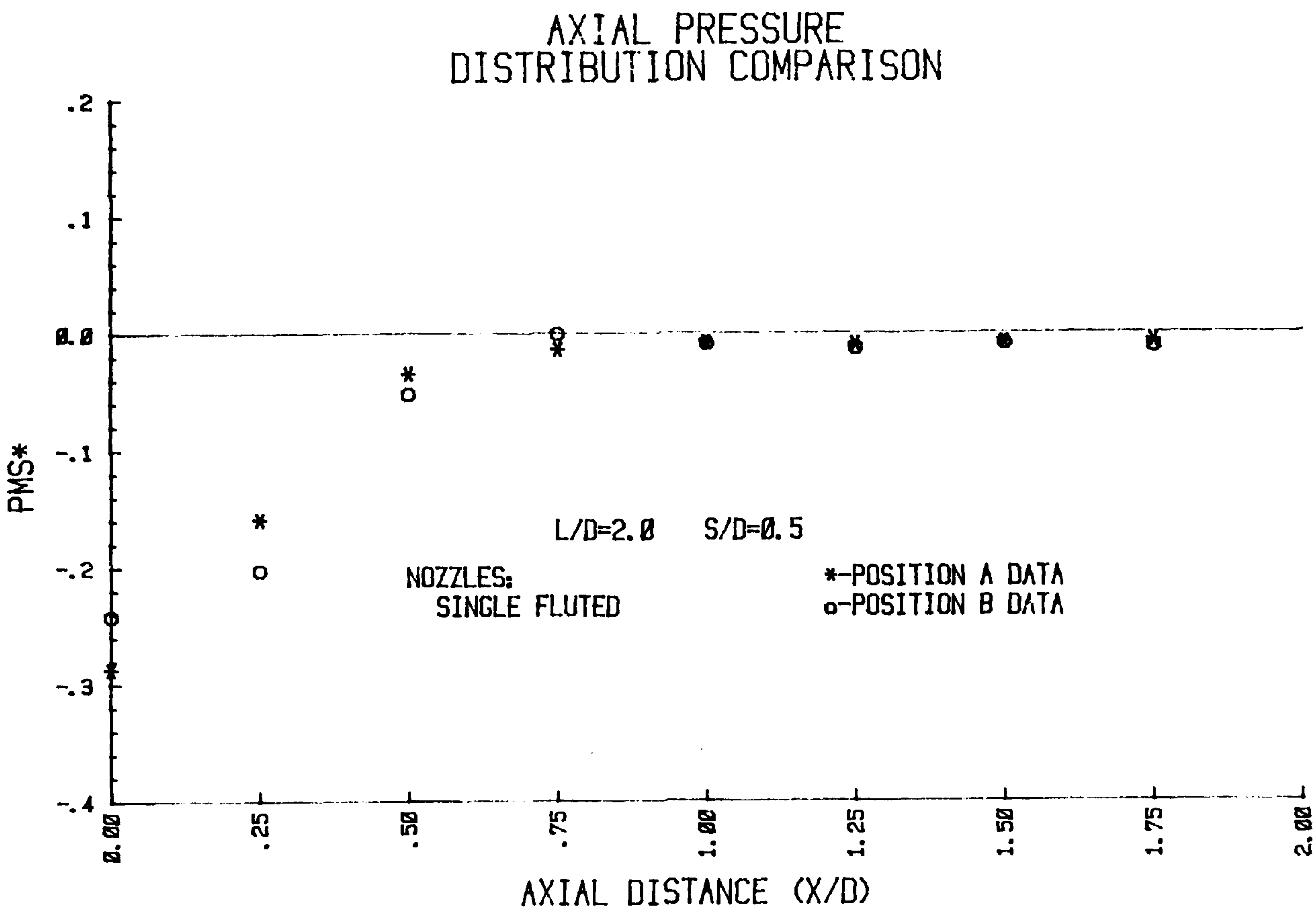


Figure 43. (contd) MSD

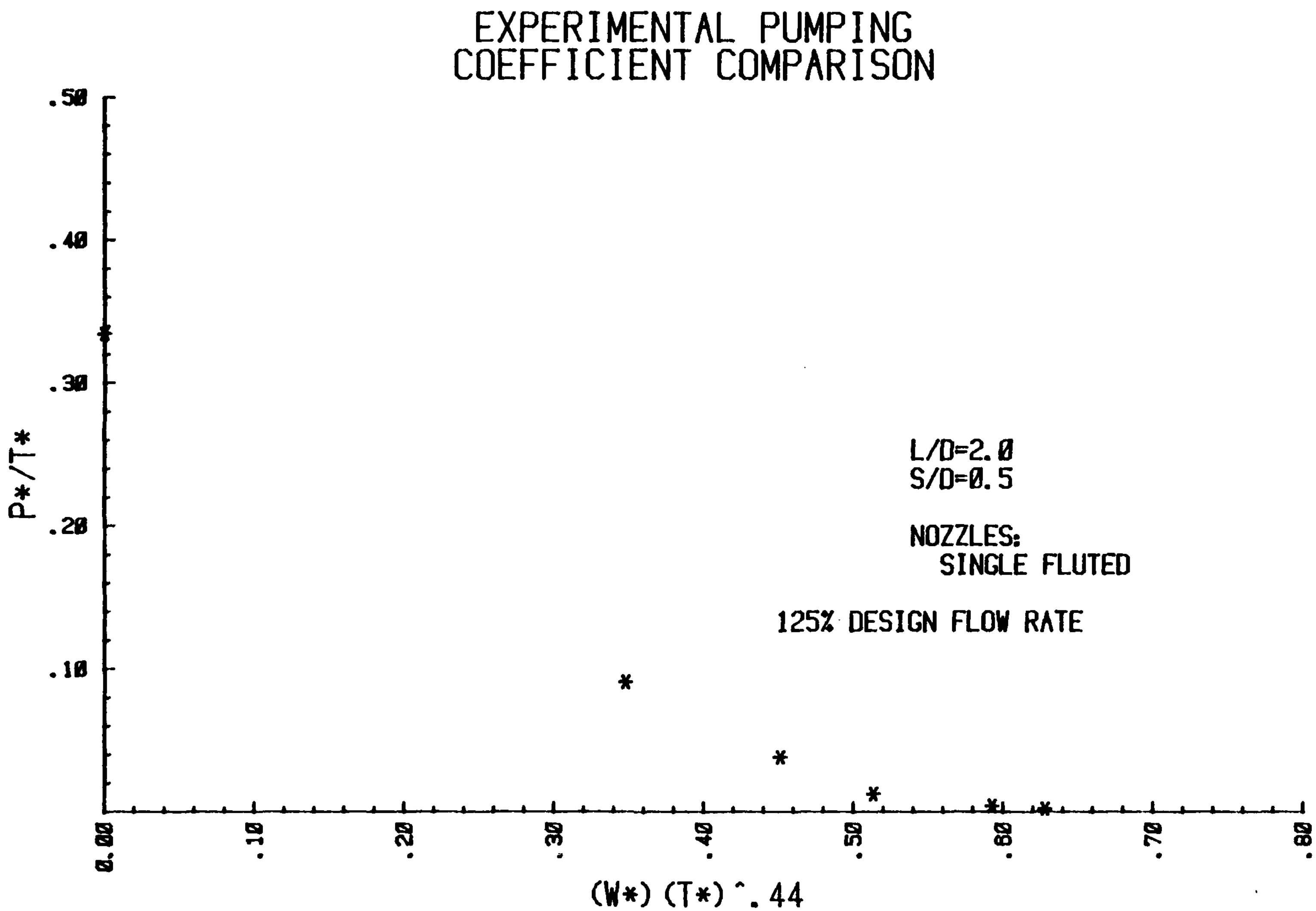


Figure 44. 125 Percent Design Flow Rate

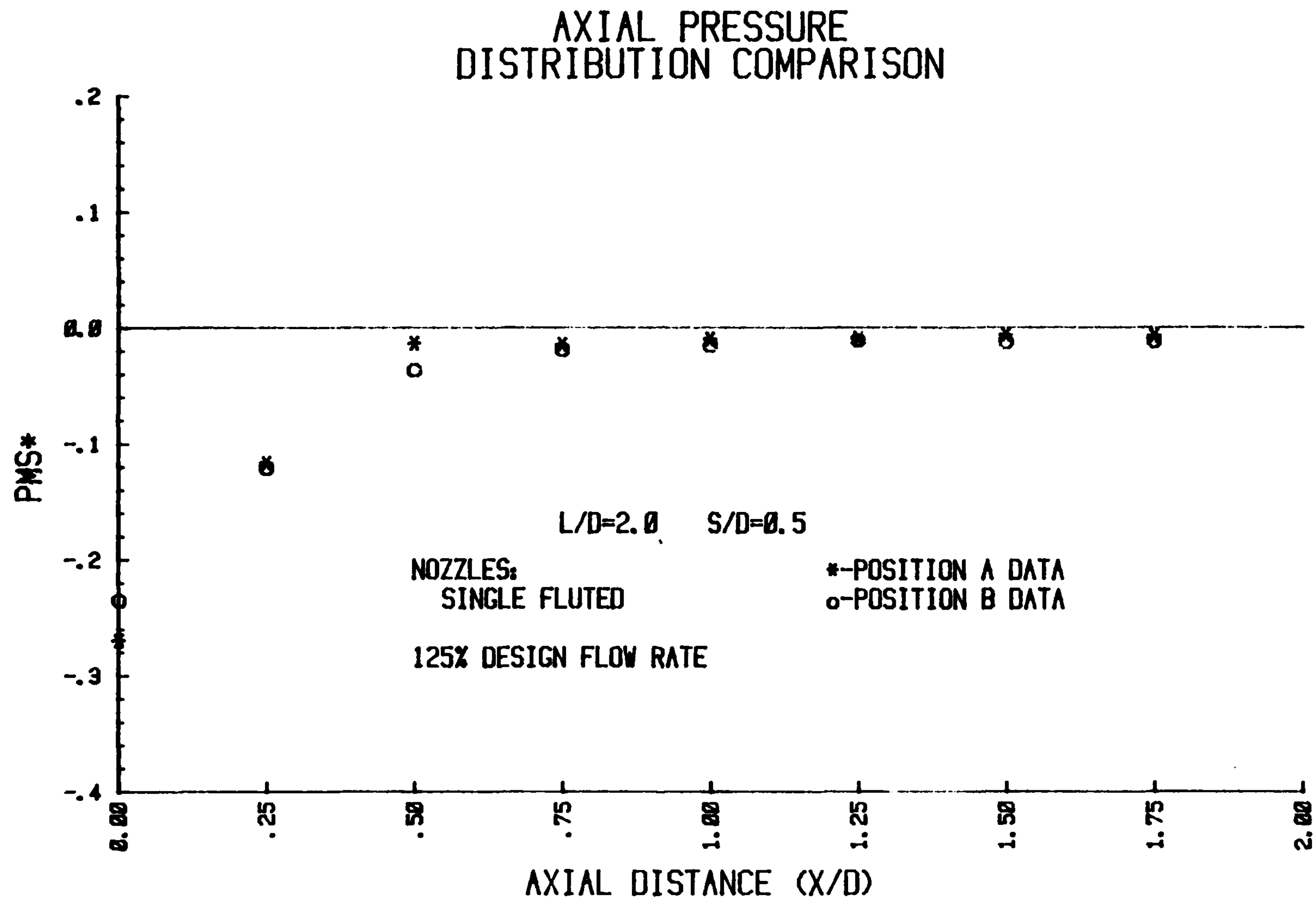


Figure 44. (contd) MSD

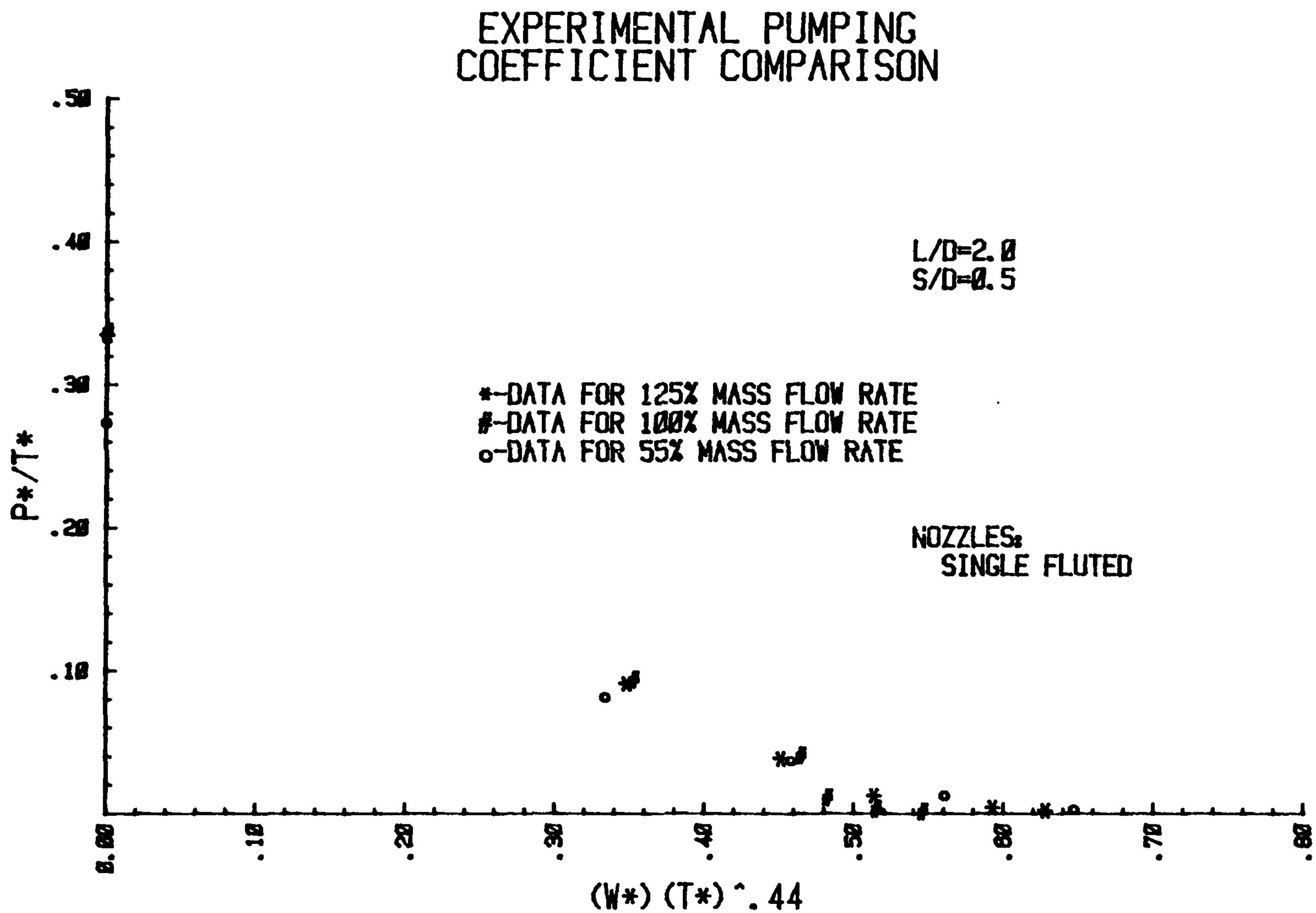


Figure 45. PCD Comparison

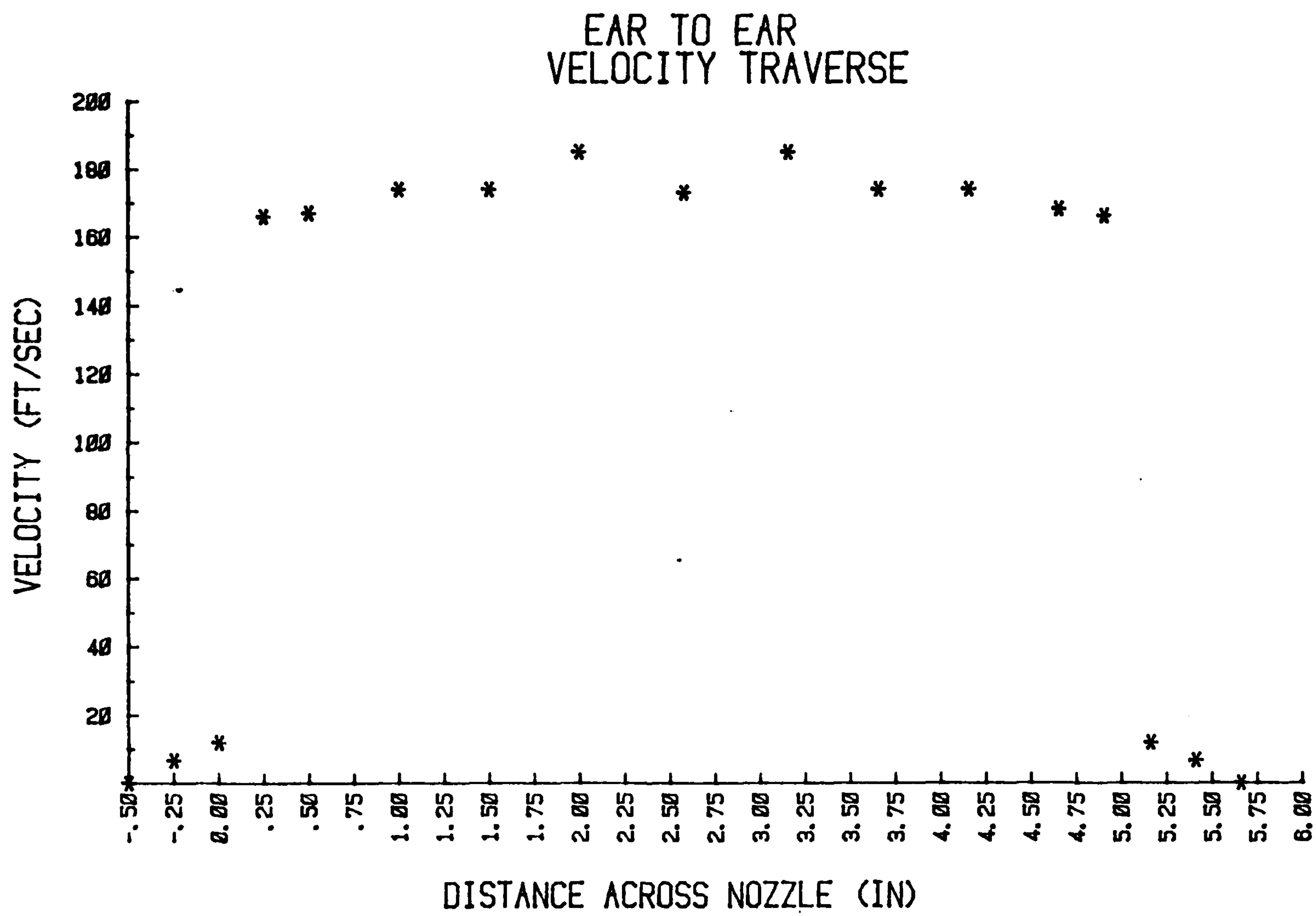


Figure 46. Ear to Ear VTD

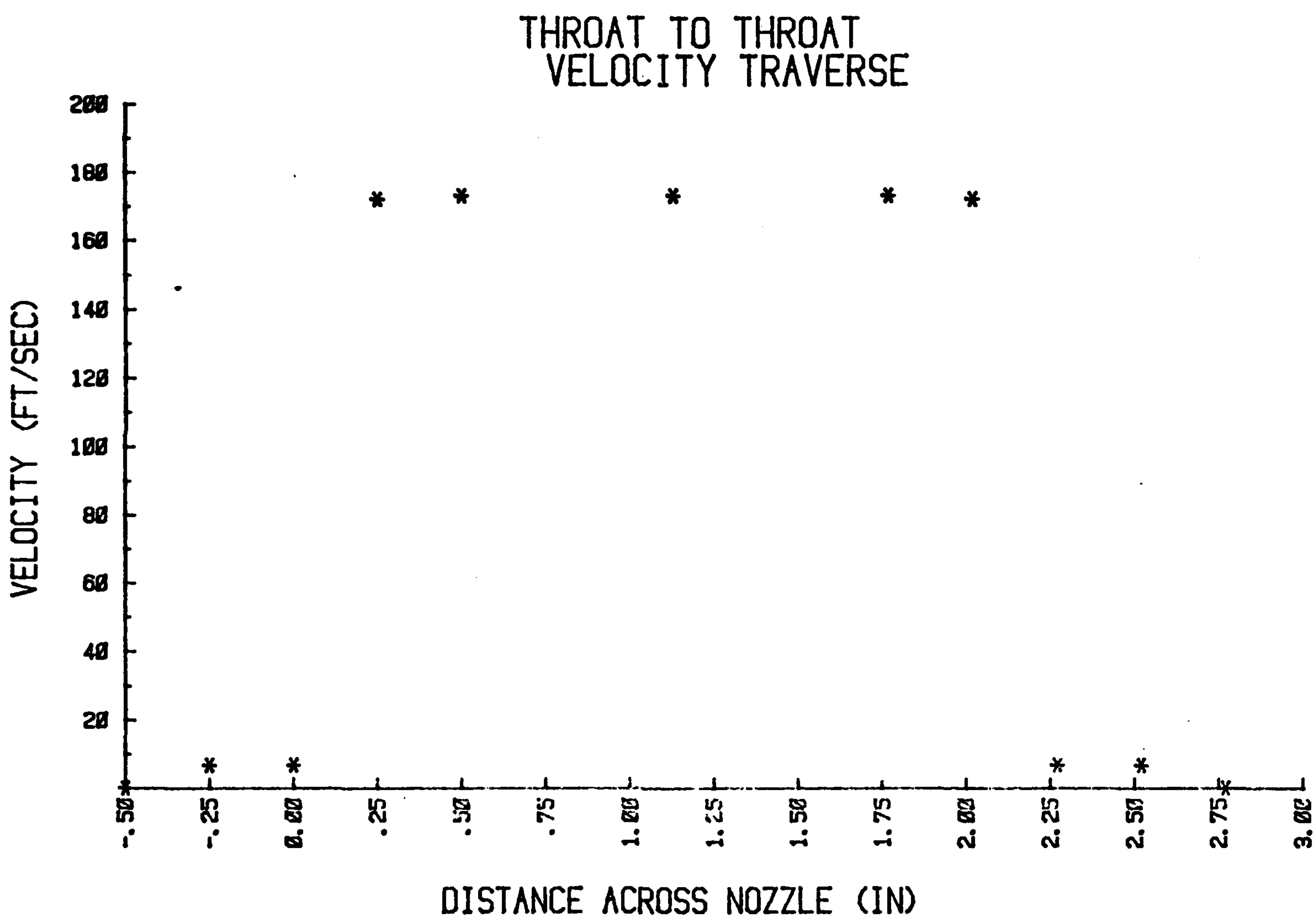


Figure 47. Throat to Throat VTD

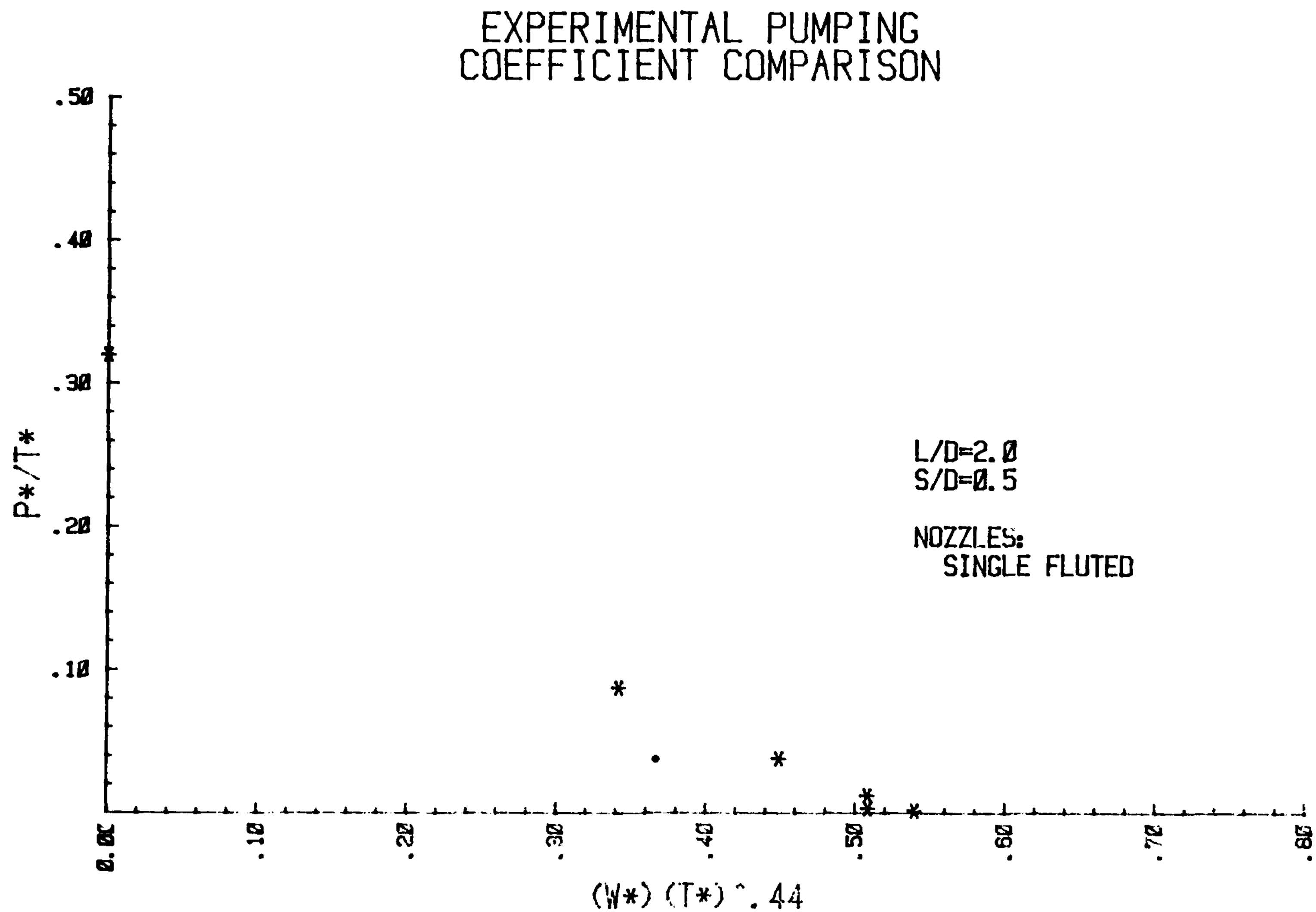


Figure 48. Single Fluted Nozzle: L/D = 2.0

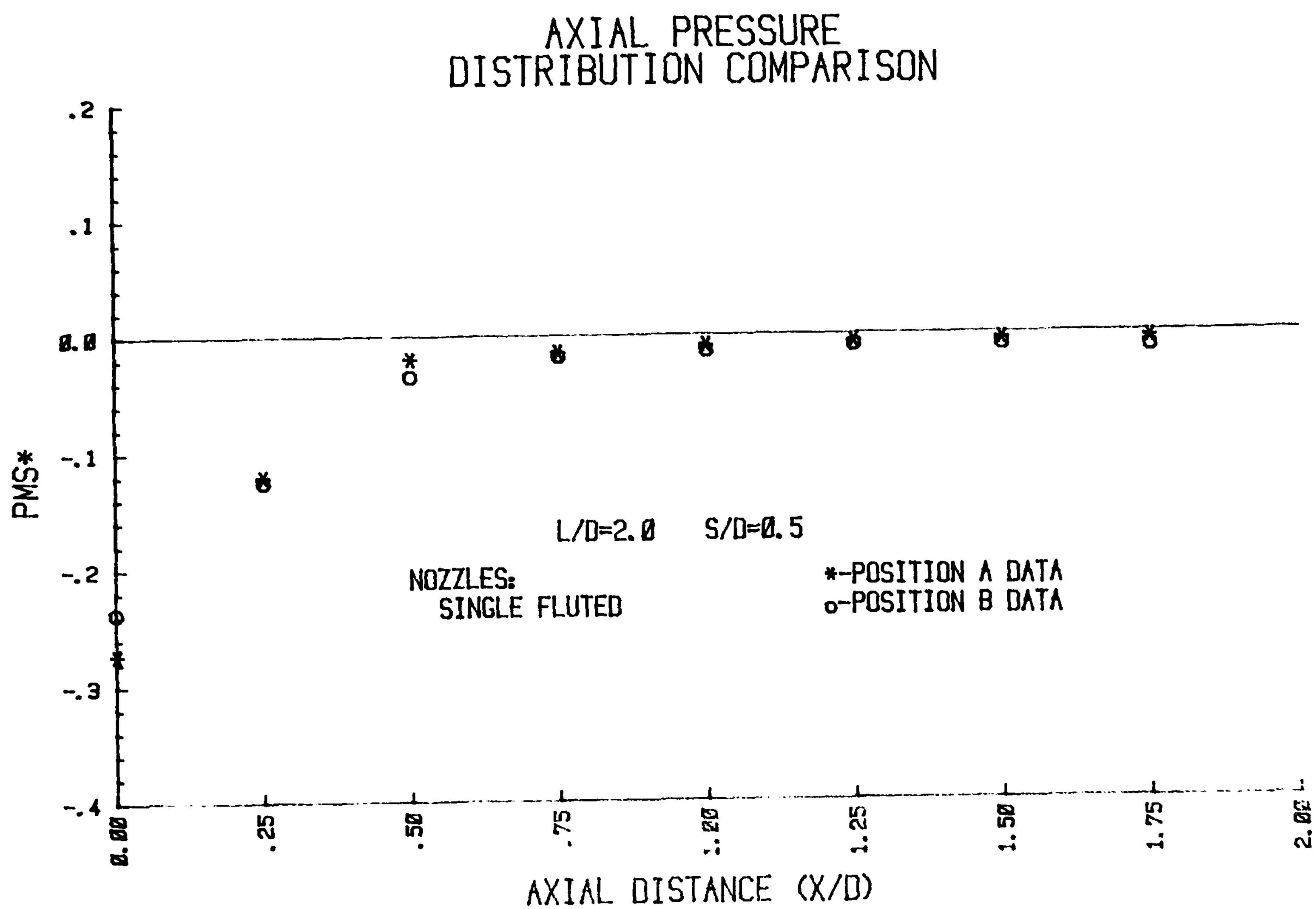


Figure 48. (contd) MSD

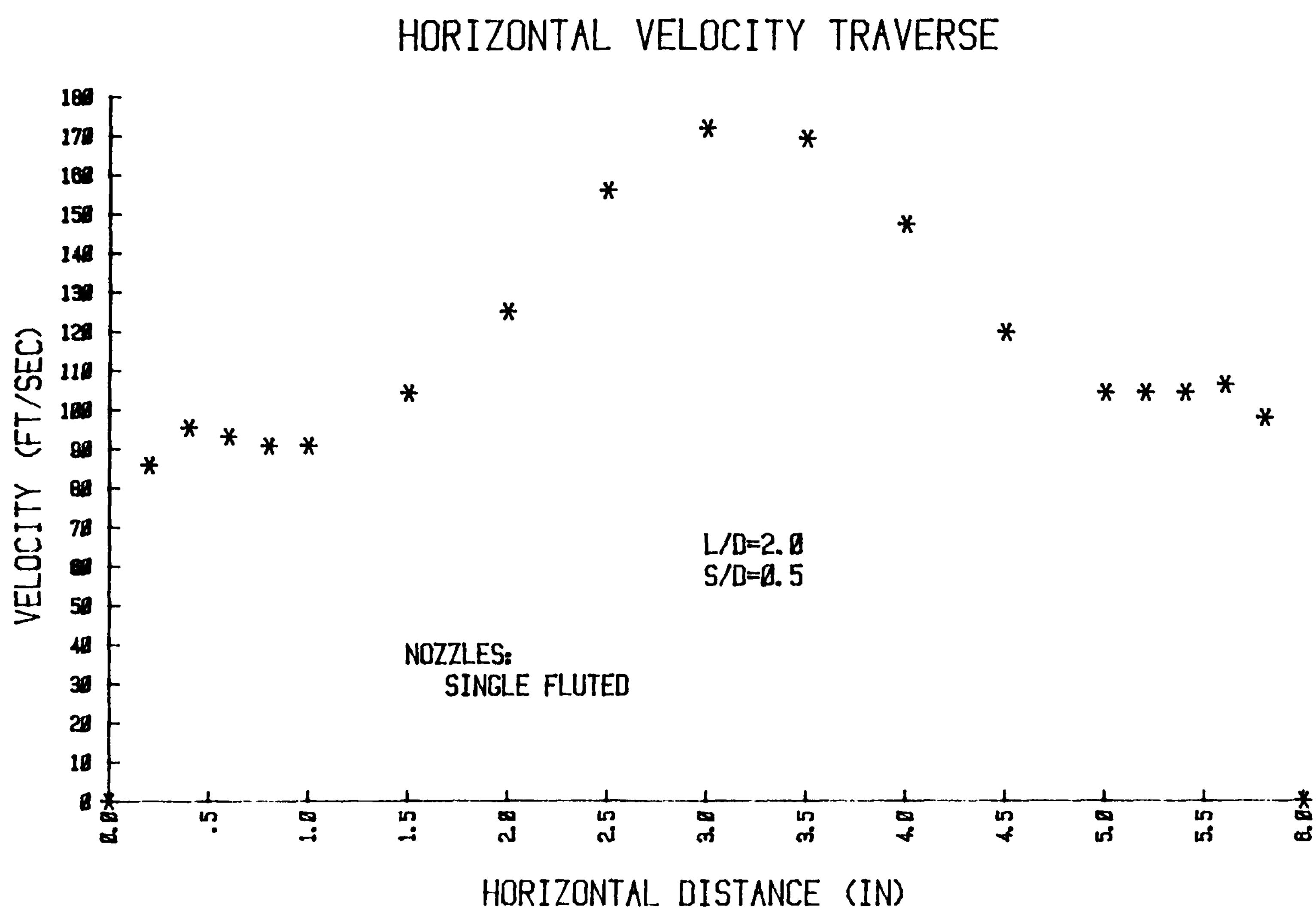


Figure 48. (contd) VTD

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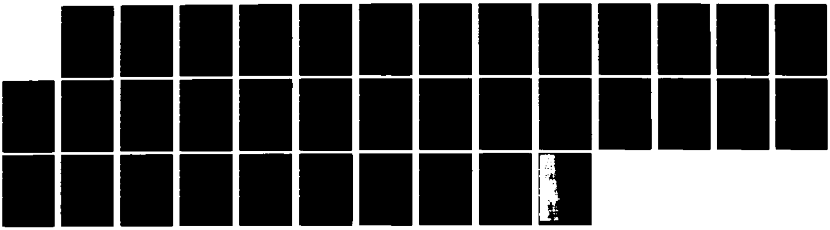

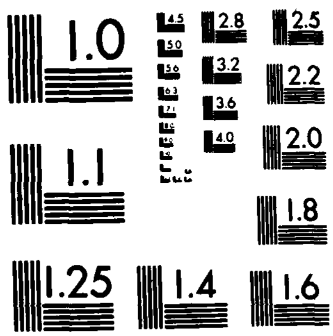

MICROCOPY RESOLUTION TEST CHART
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DIAGONAL VELOCITY TRAVERSE

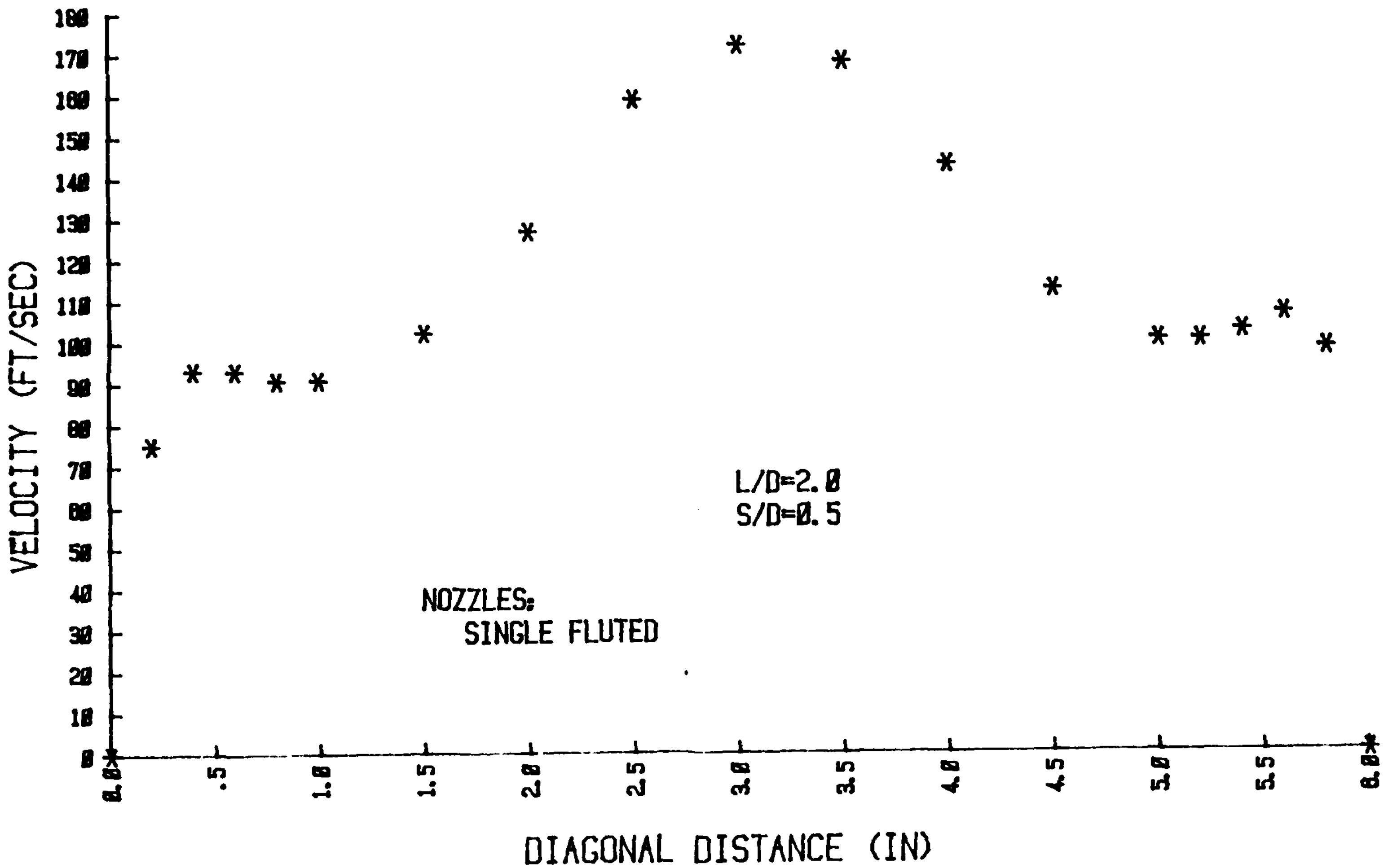


Figure 48. (contd) VTD

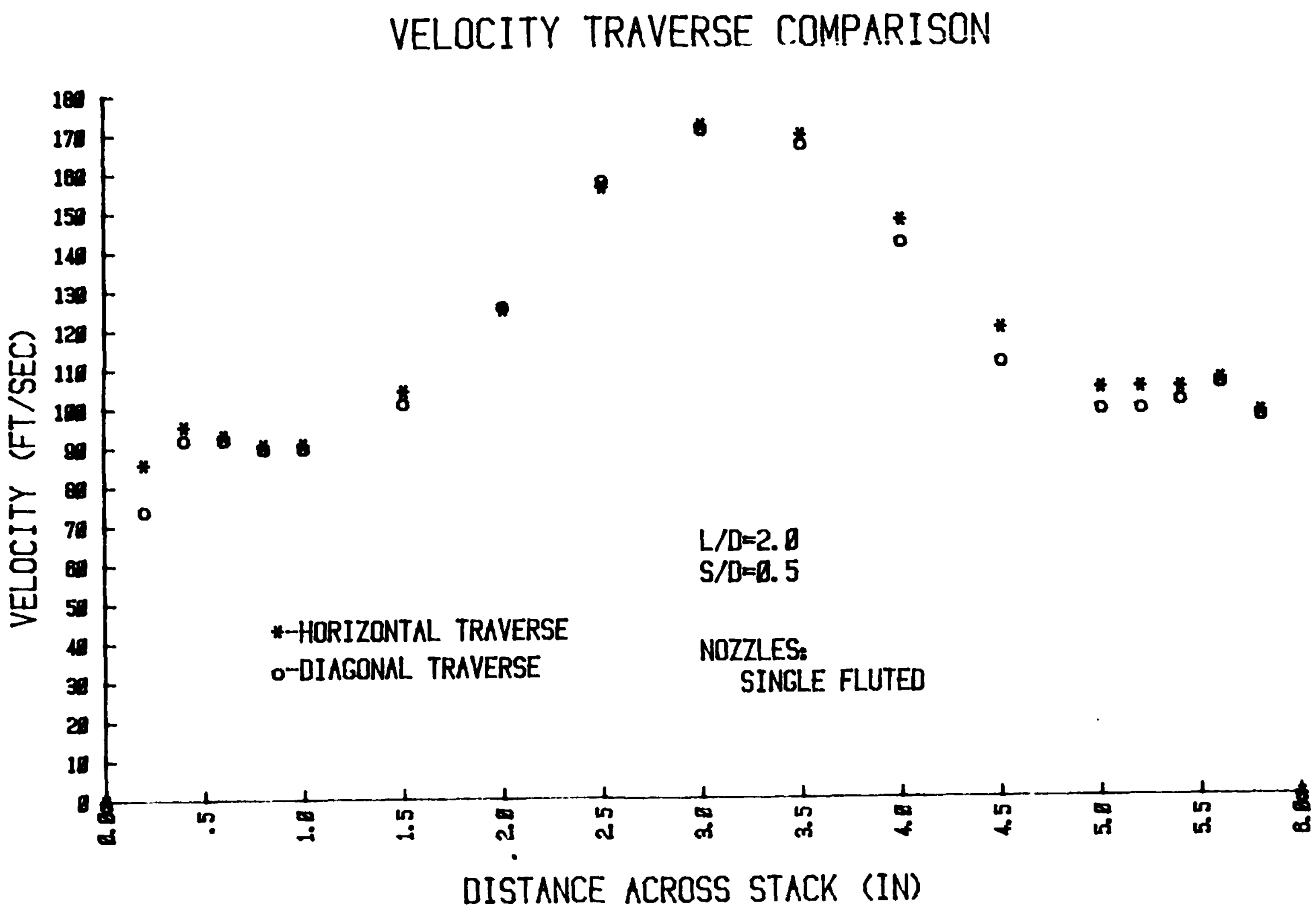


Figure 48. (contd) VTD Comparison

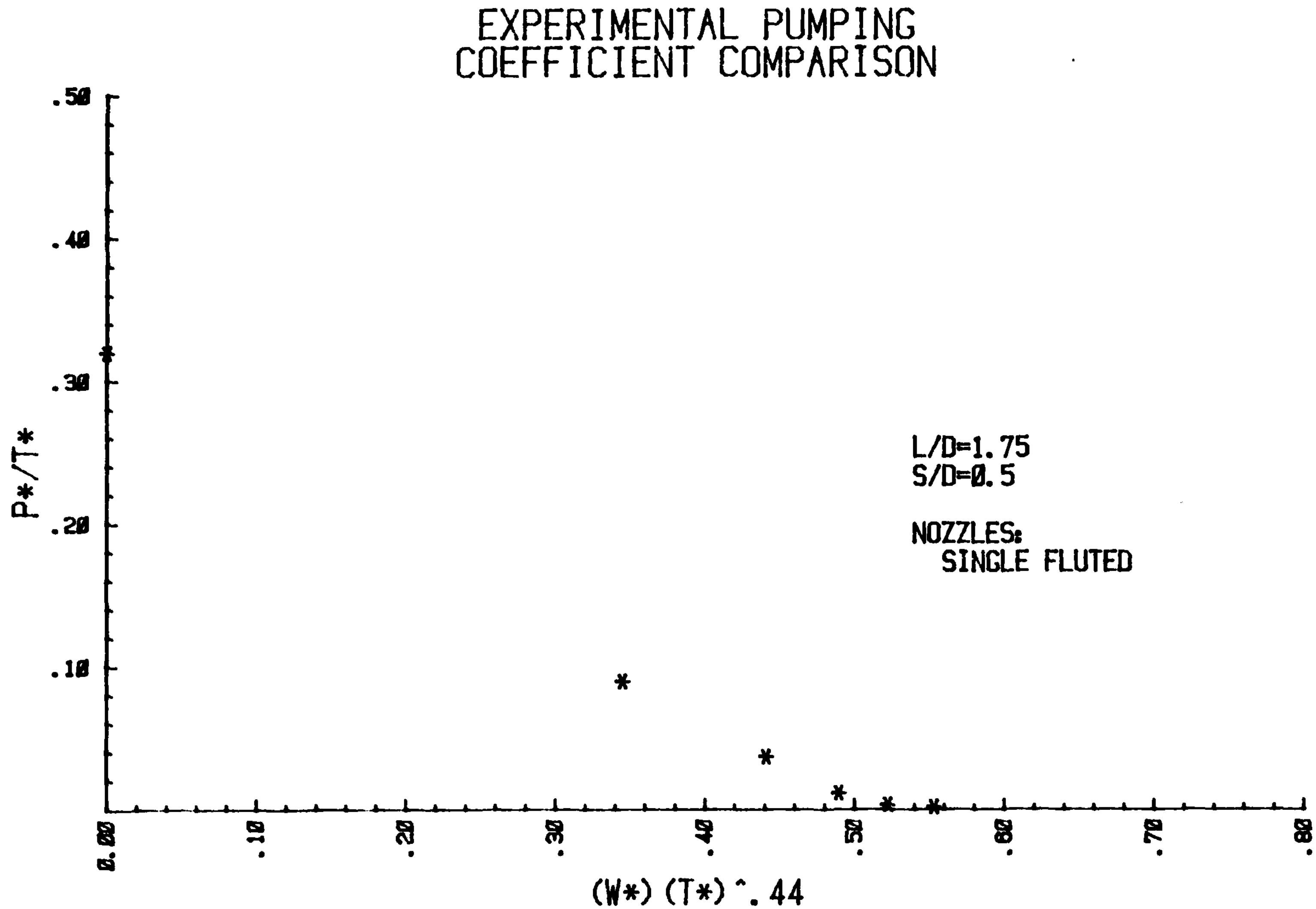


Figure 49. Single Fluted Nozzle: L/D = 1.75

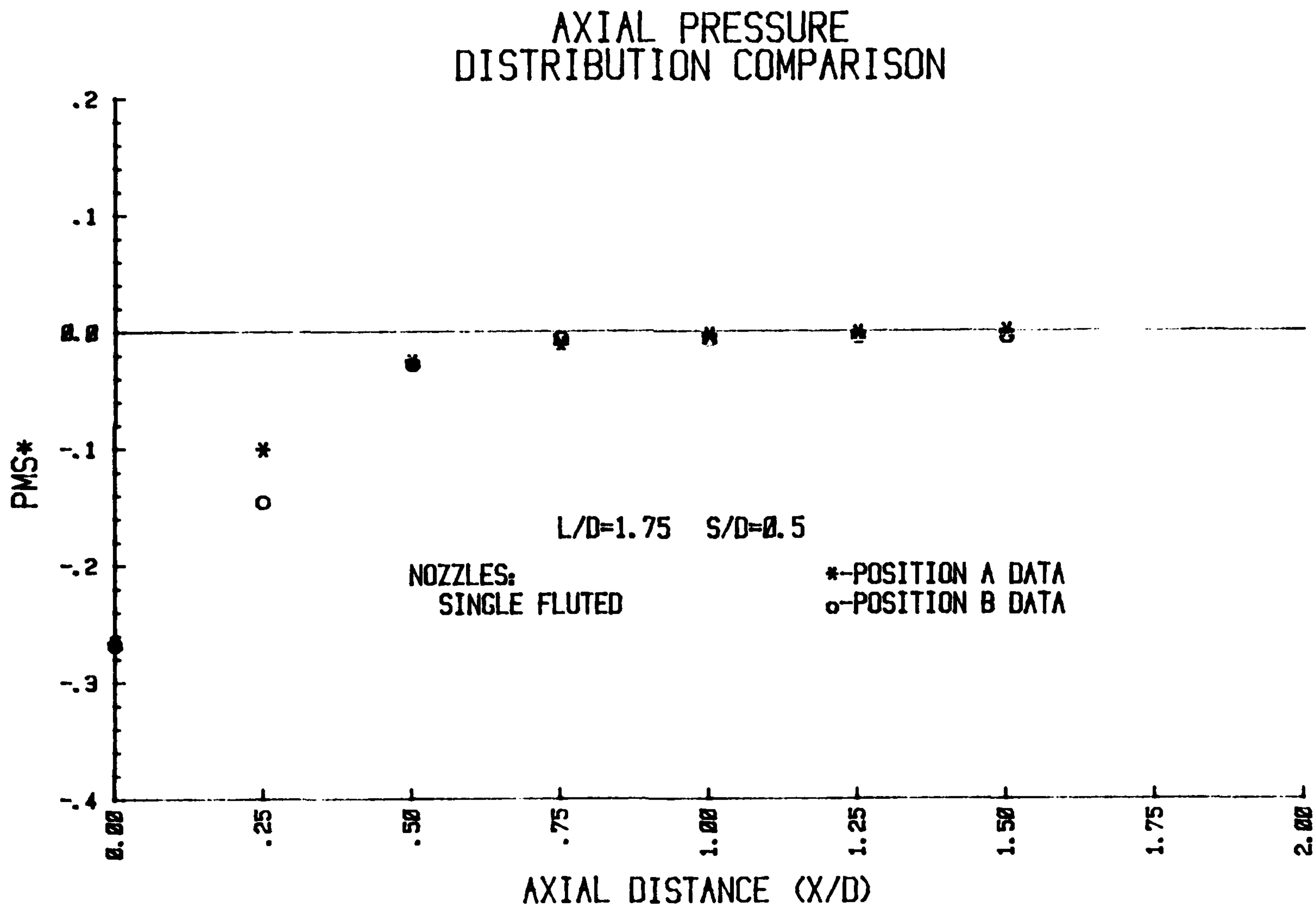
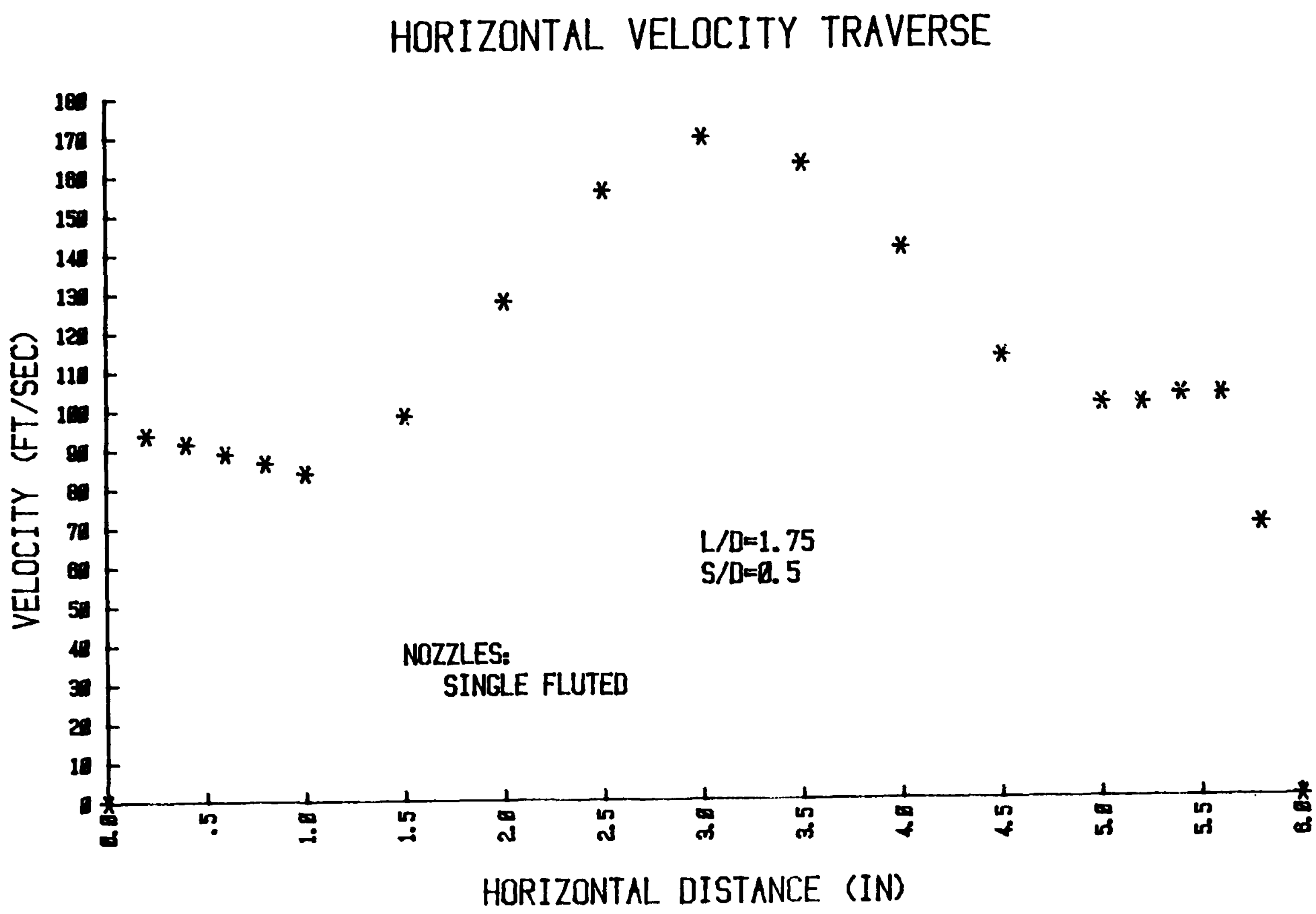


Figure 49. (contd) MSD



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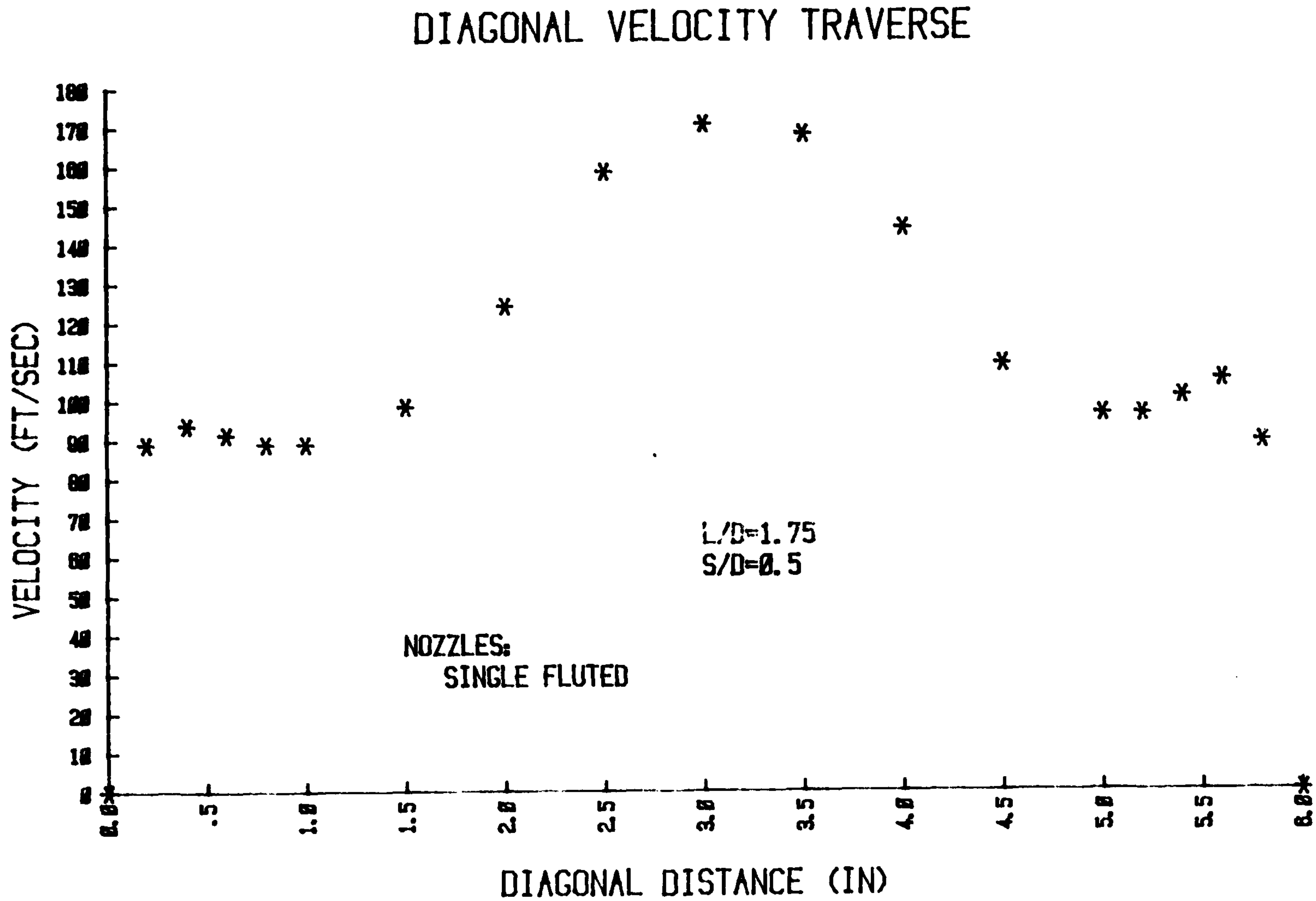

Figure 49. (contd) VTD

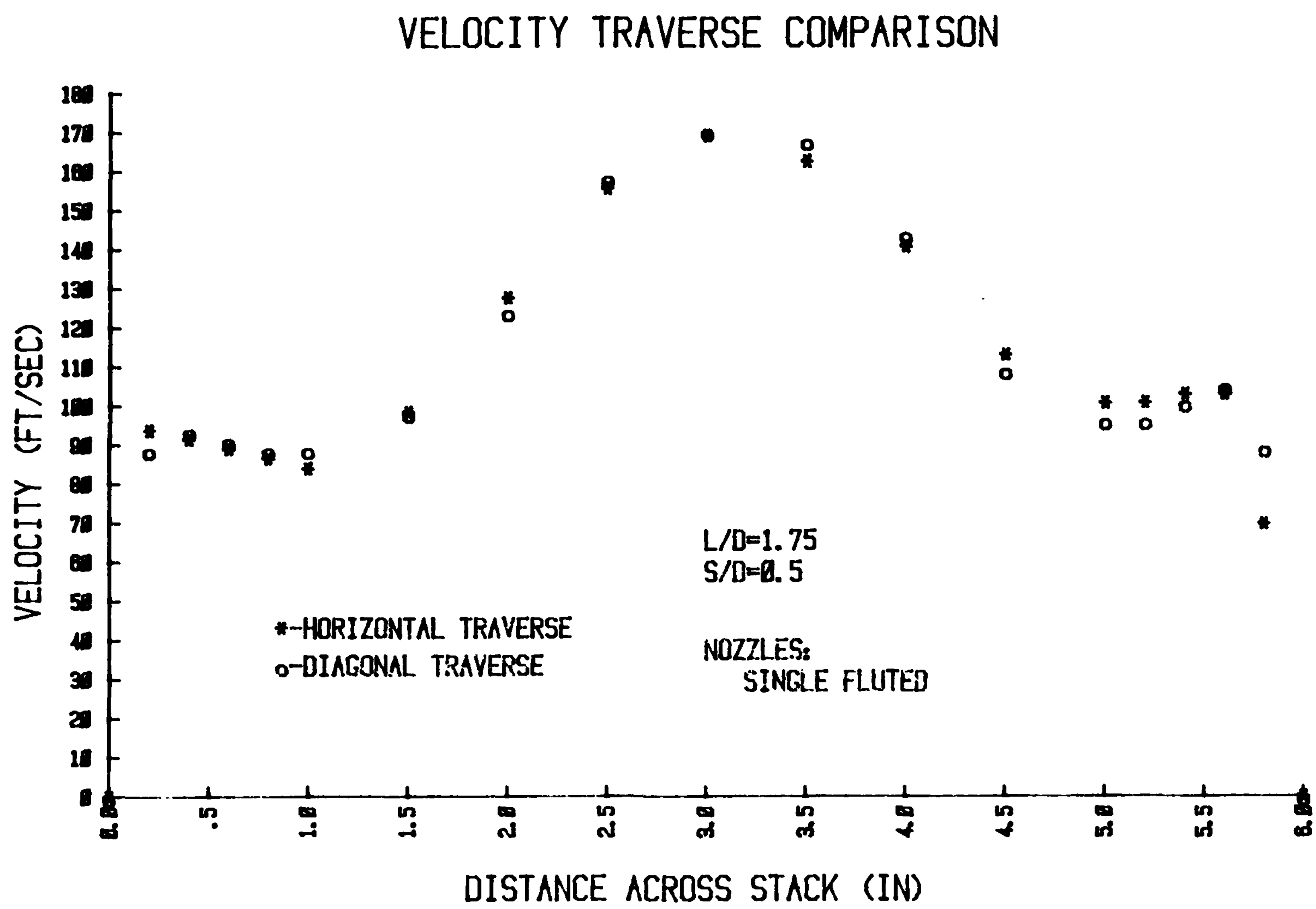

Figure 49. (contd) VTD Comparison

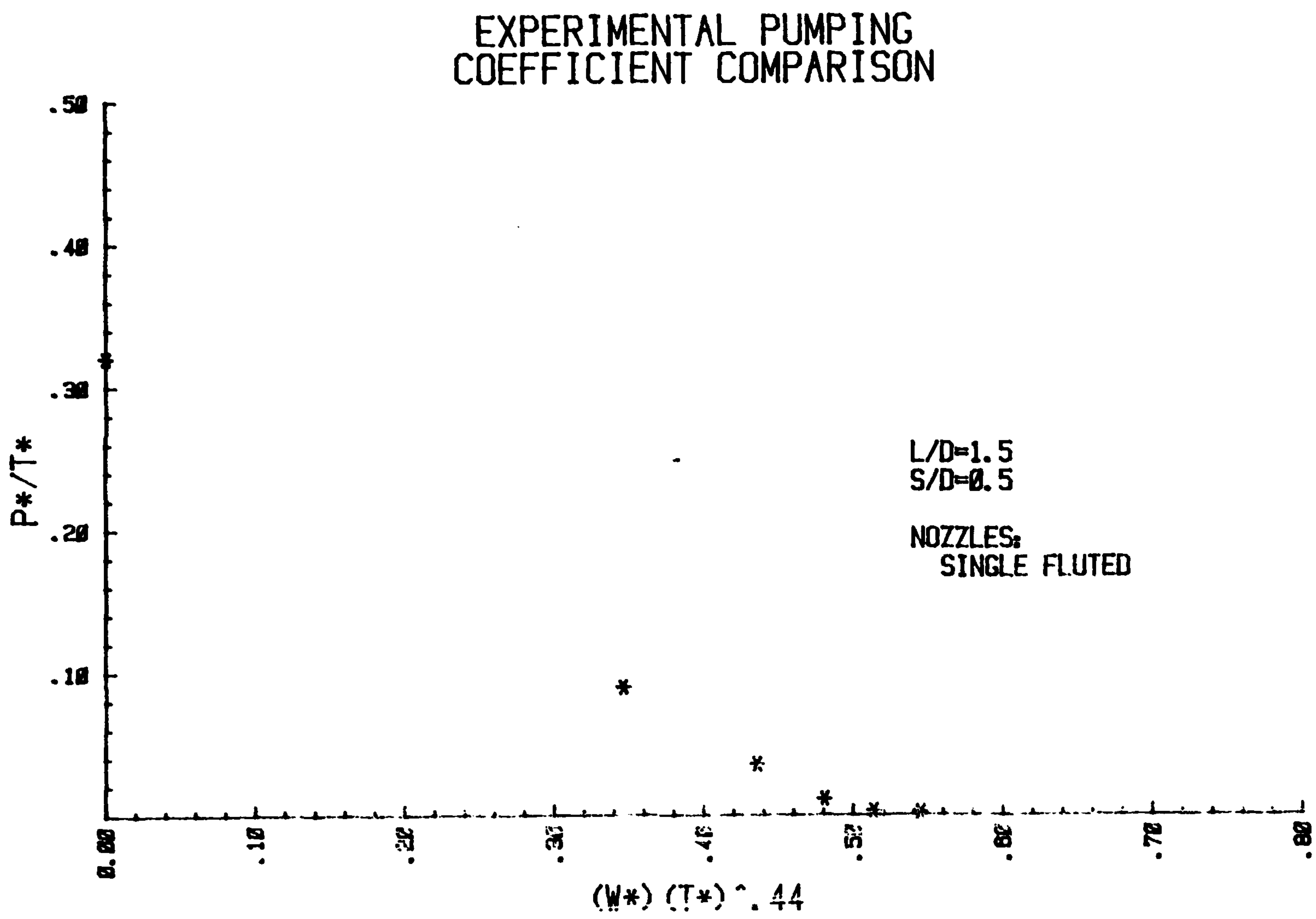

Figure 50. Single Fluted Nozzle: L/D = 1.5

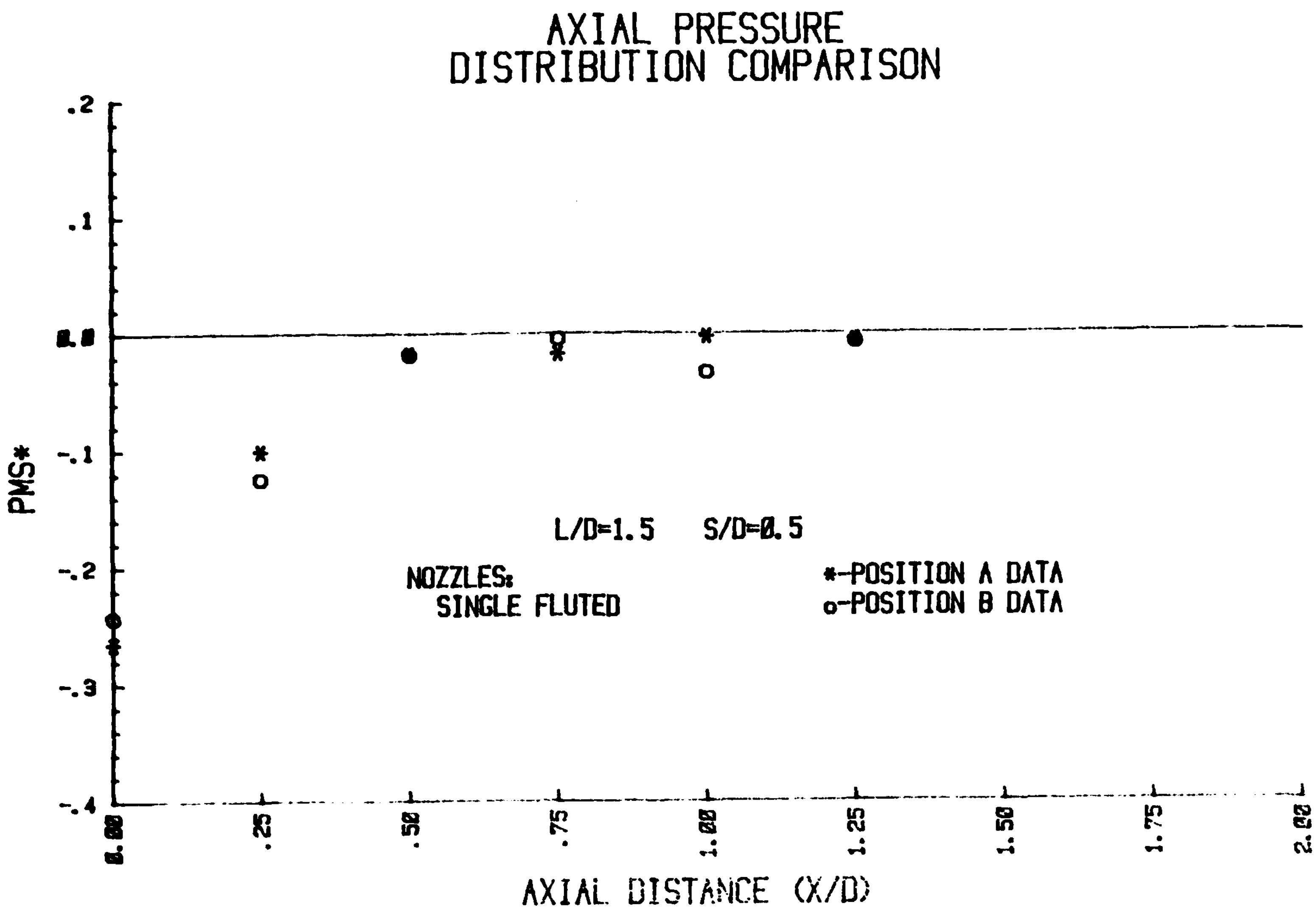

Figure 58. (contd) MSD

HORIZONTAL VELOCITY TRAVERSE

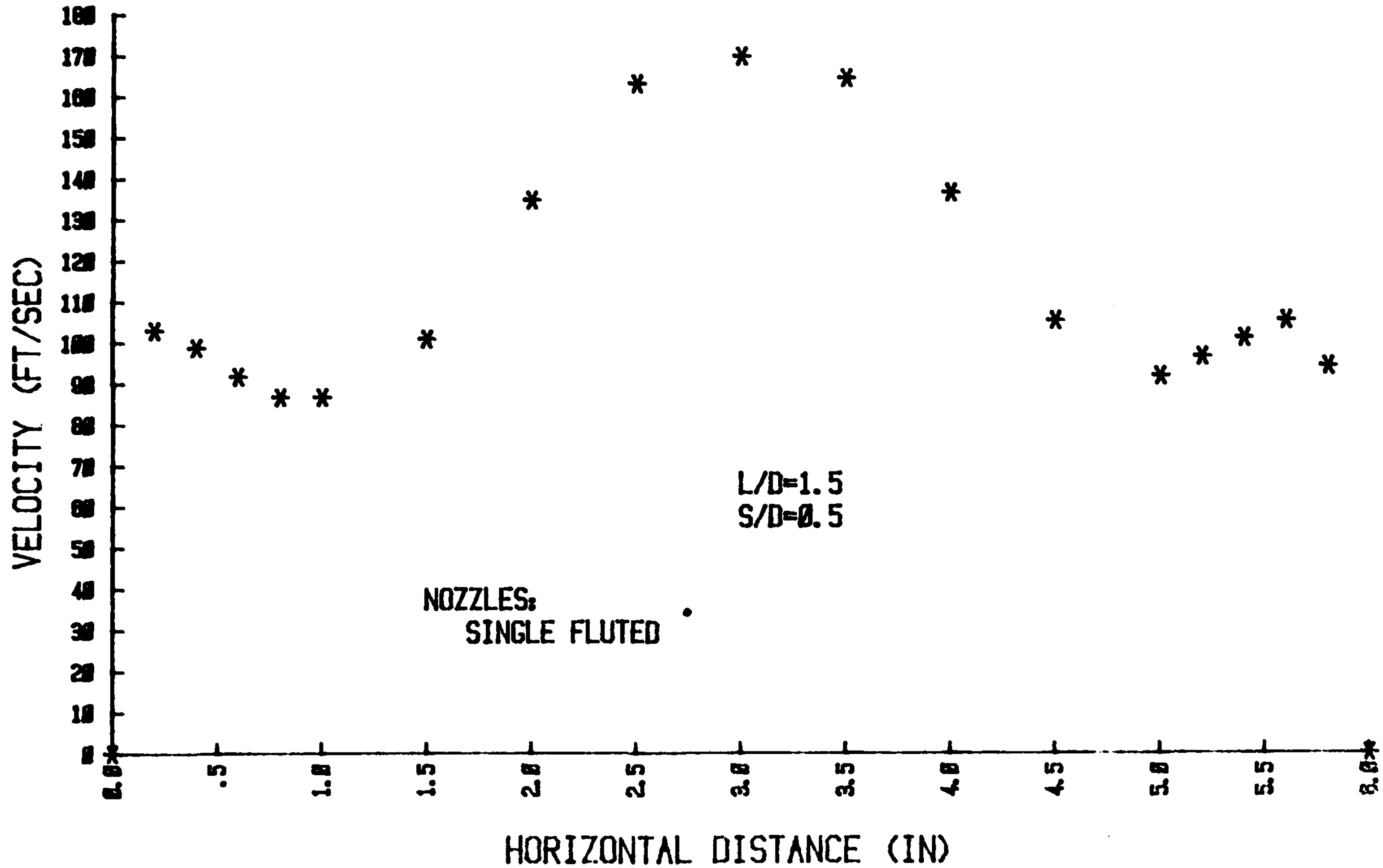

Figure 50. (contd) VTD

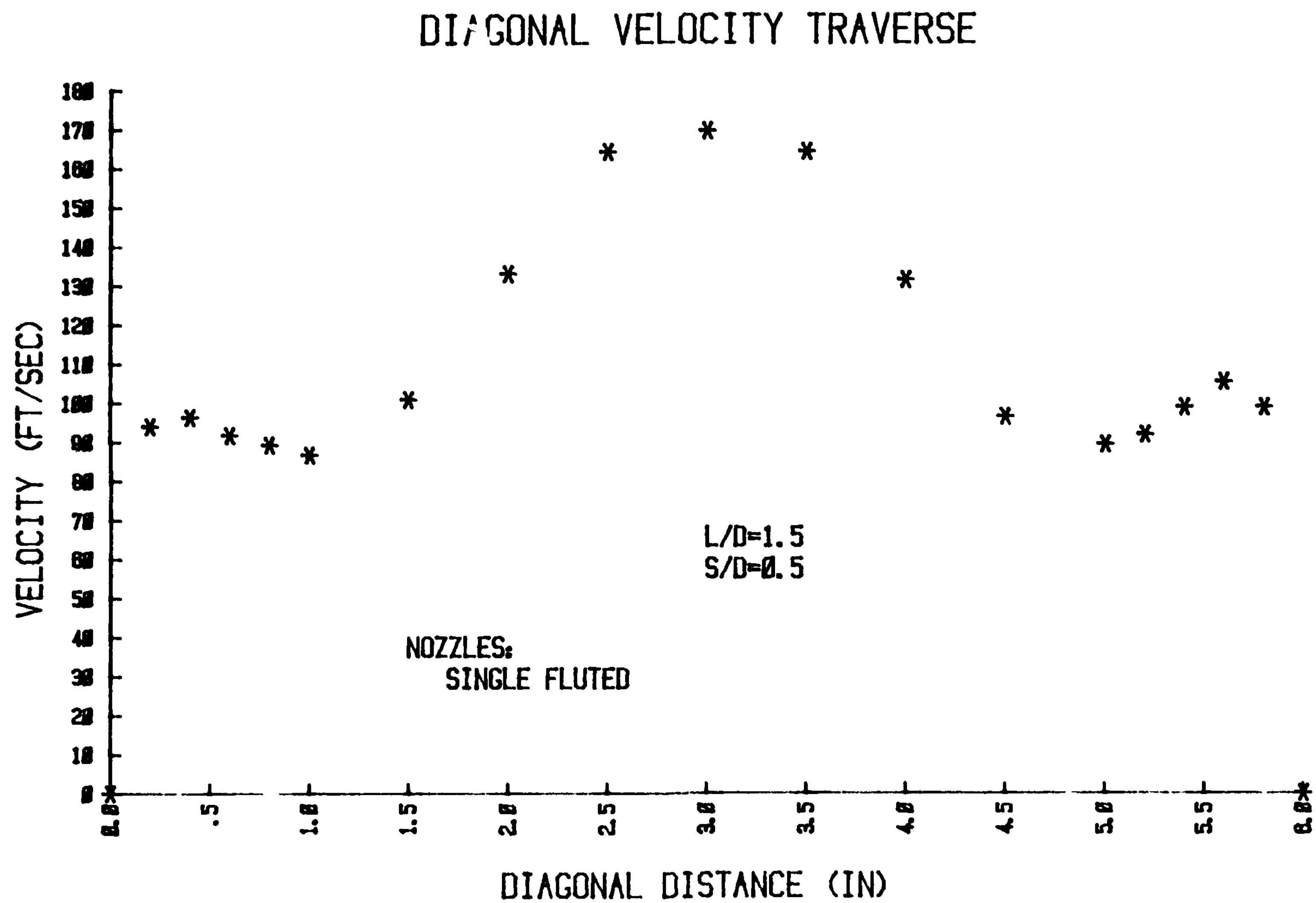

Figure 50. (contd) VTD

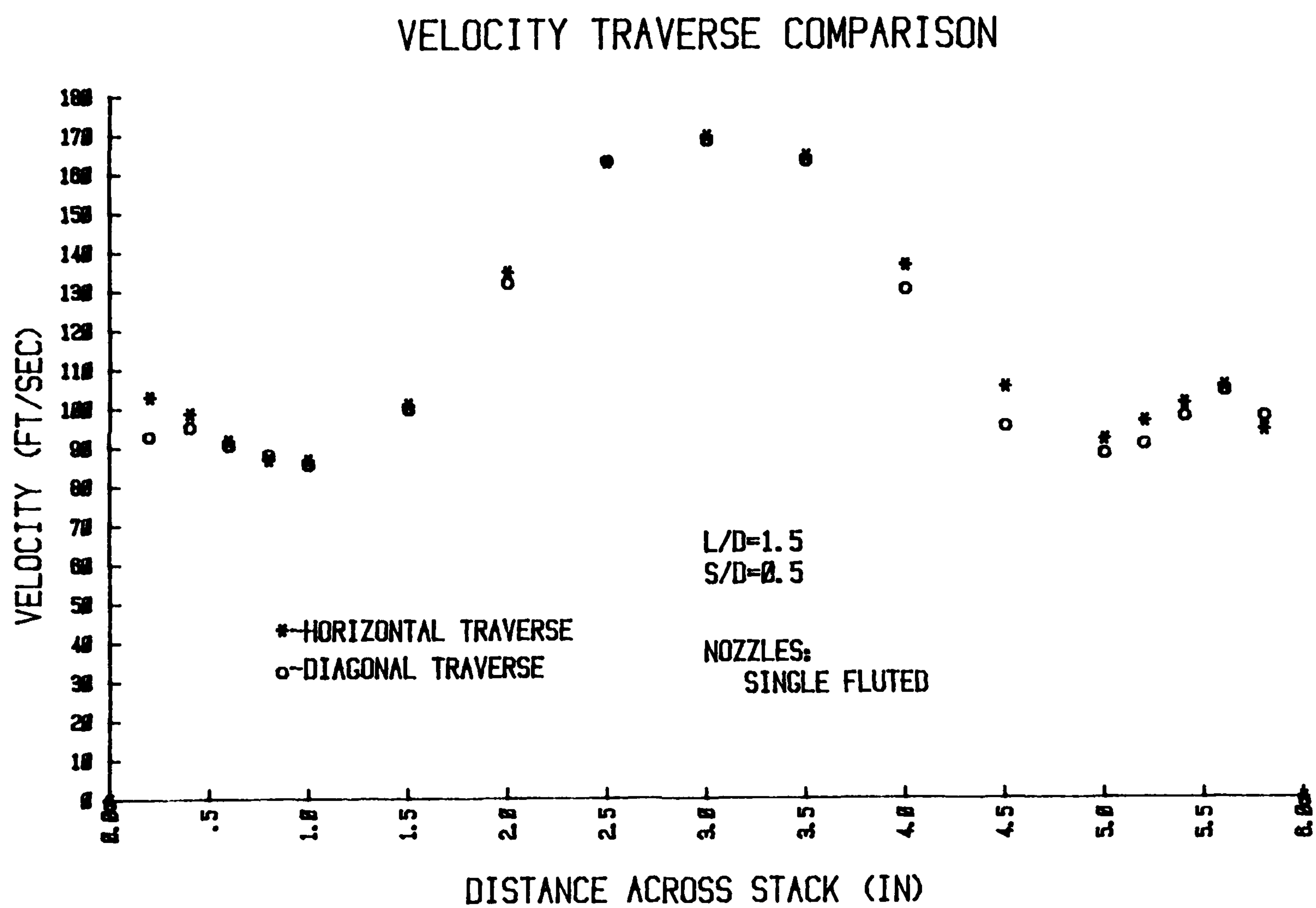

Figure 50. (contd) VTD Comparison

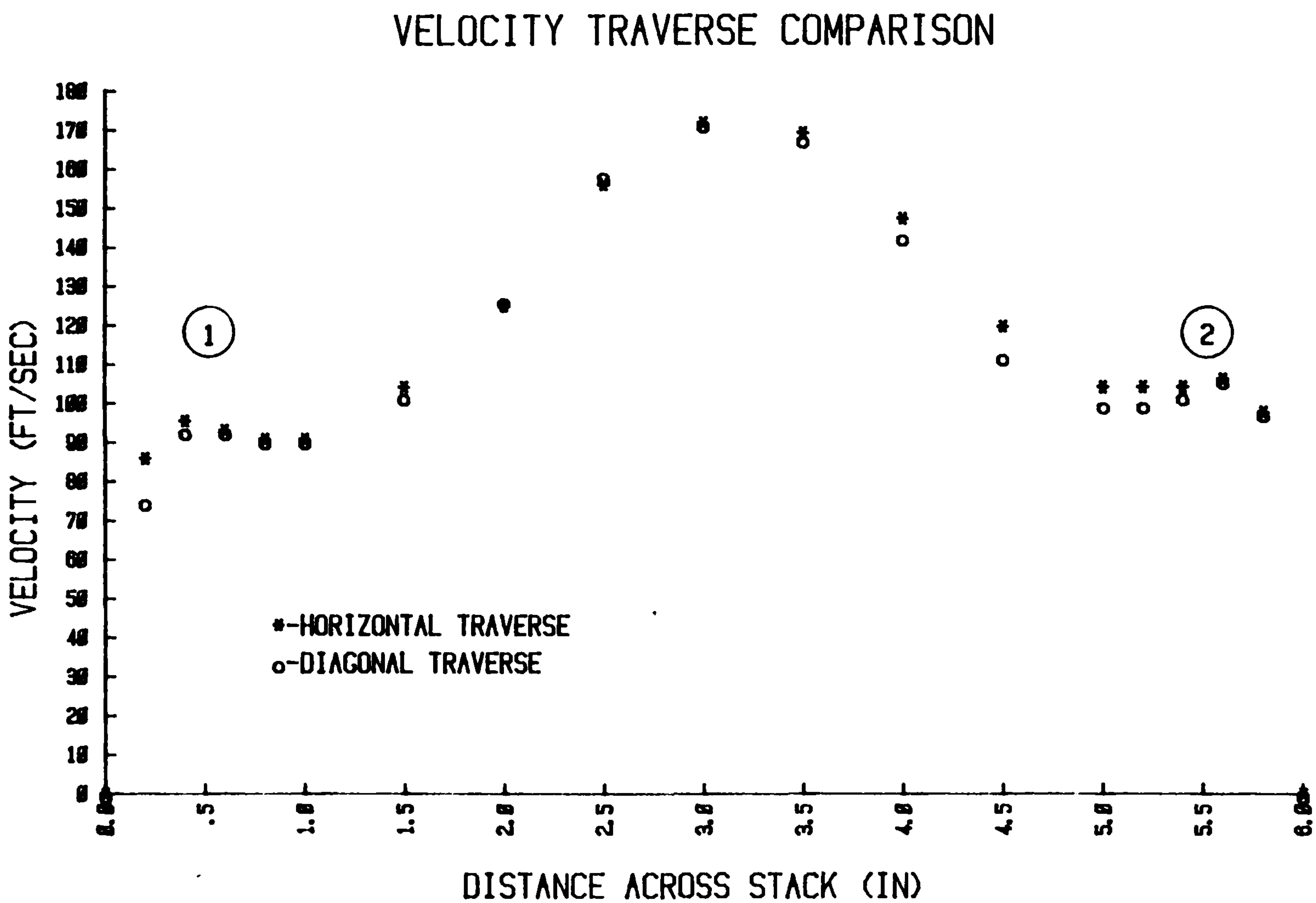

Figure 51. Sample Velocity Profile Comparison Plot

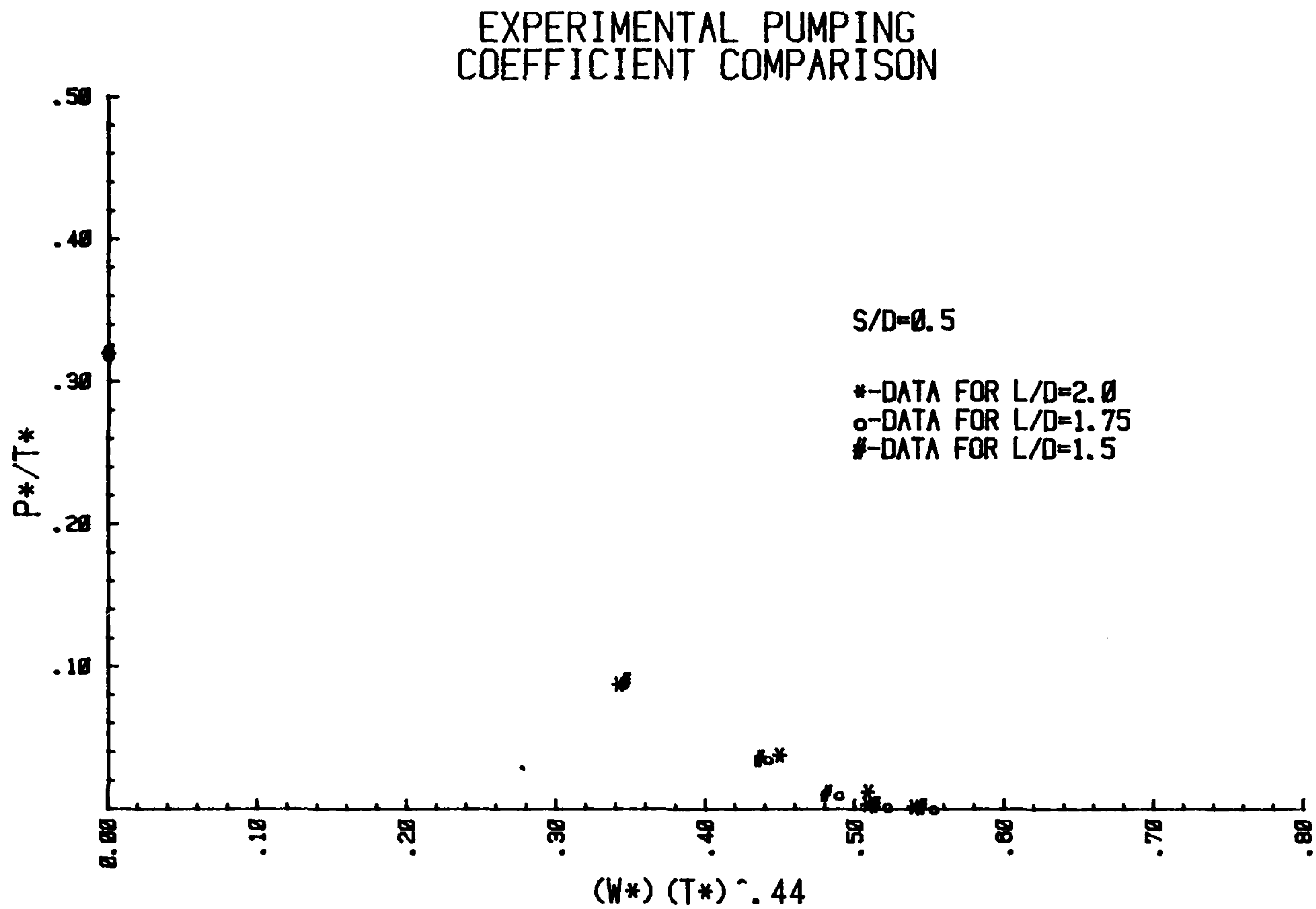

Figure 52. PCD vs L/D (Single)

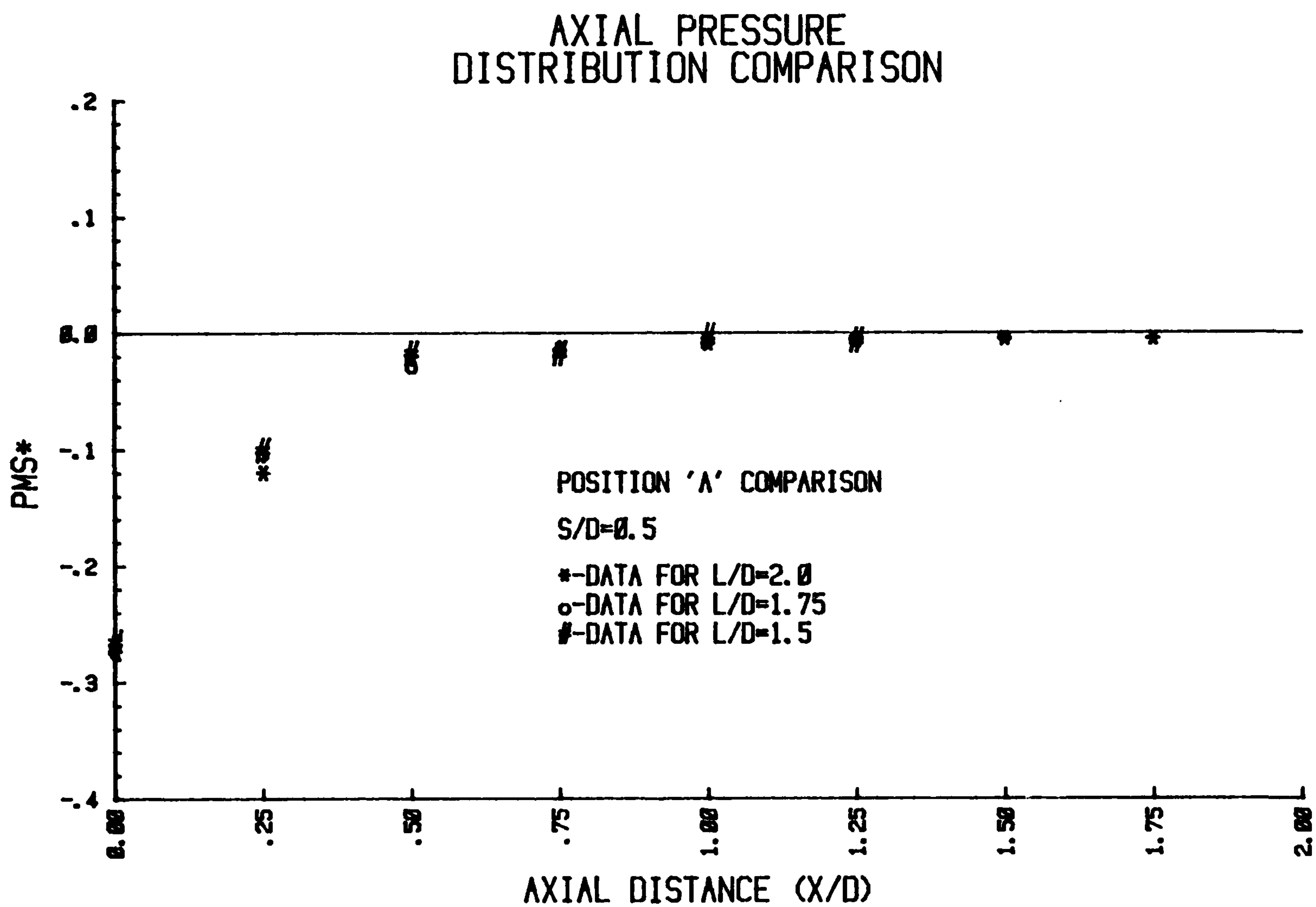

Figure 53. MSD vs L/D (Single)

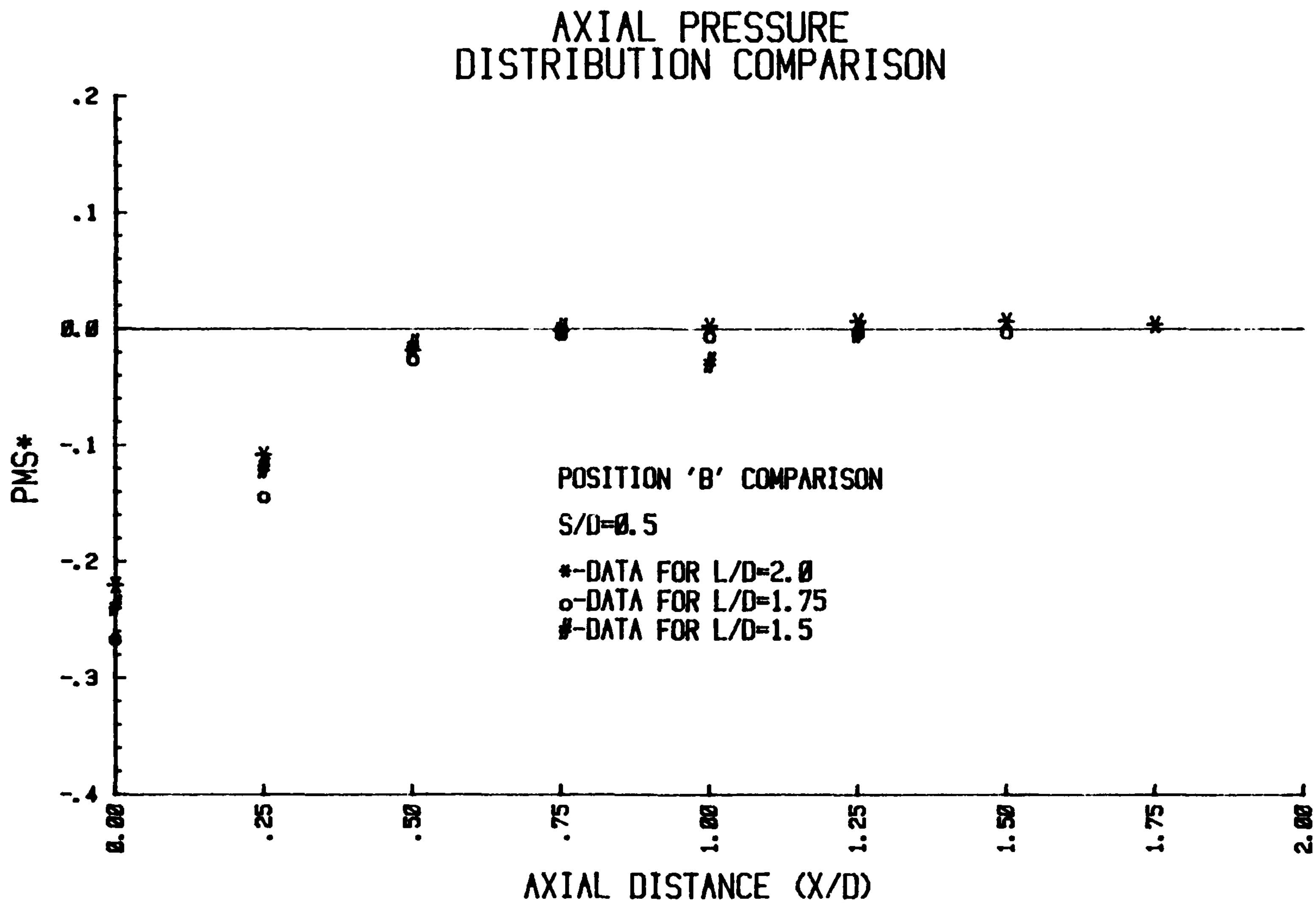

Figure 53. (contd)

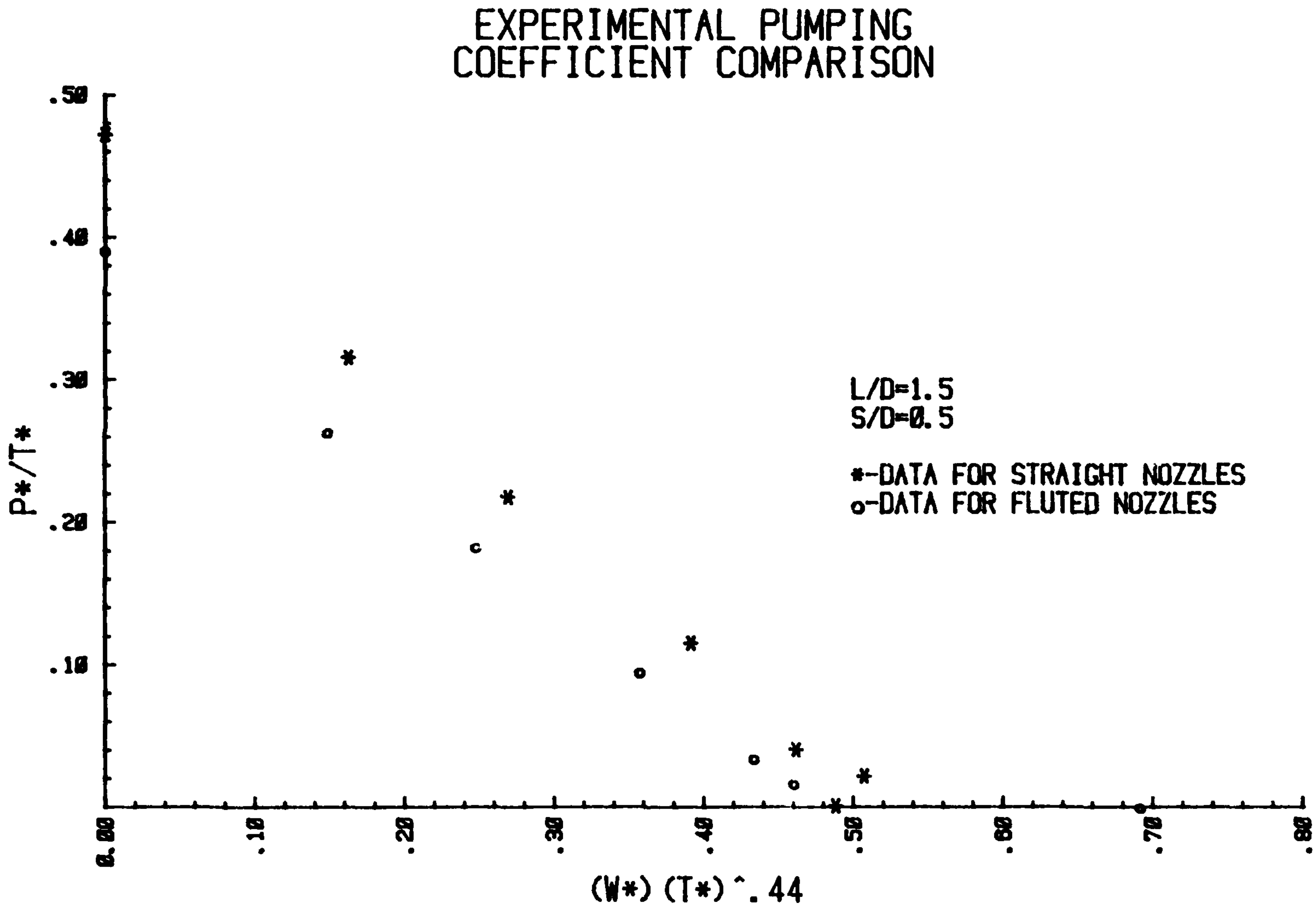

Figure 54. Straight vs Fluted (Four Nozzles)

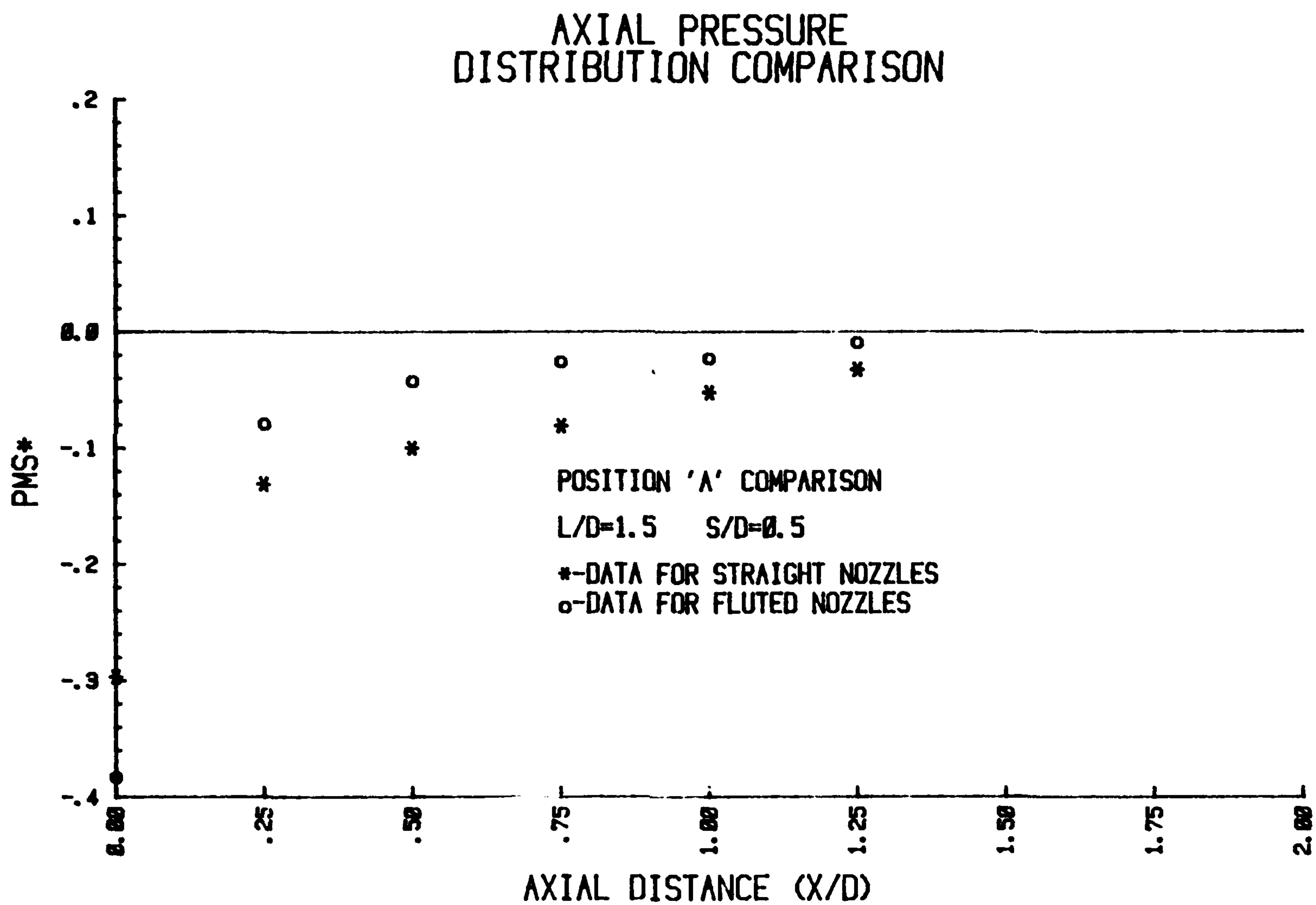

Figure 54. (contd) MSD

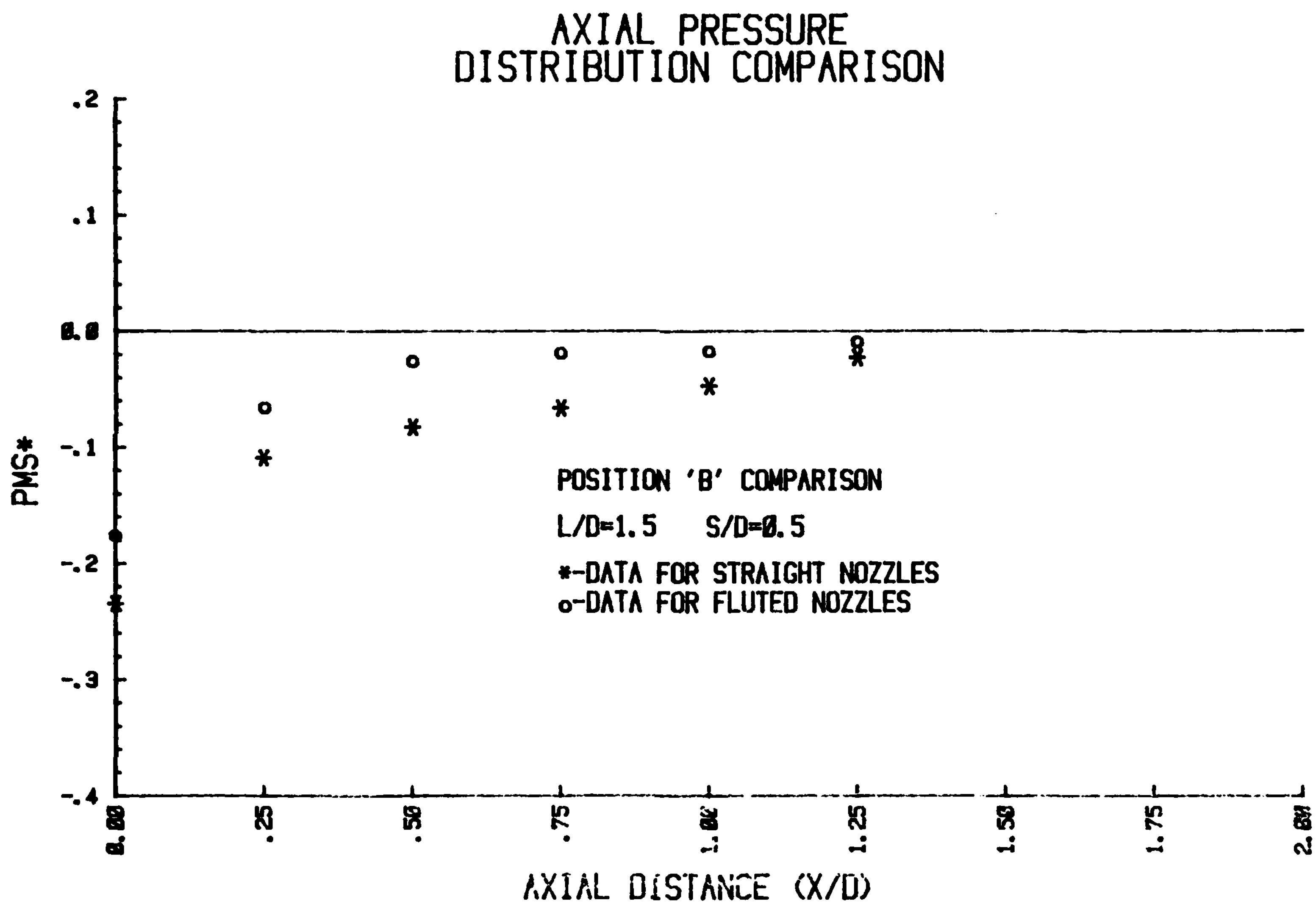

Figure 54. (contd) MSD

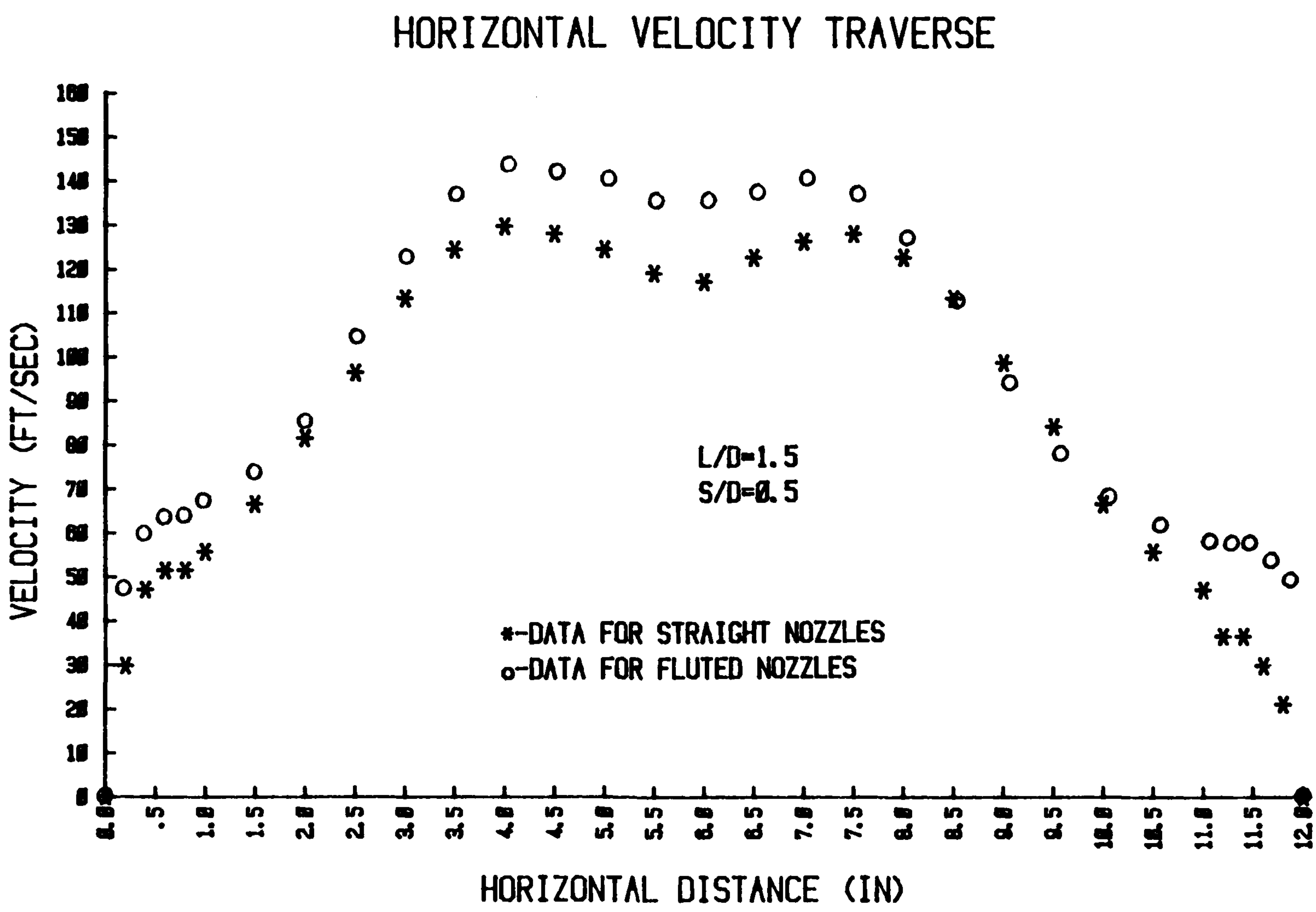

Figure 54. (contd) VTD

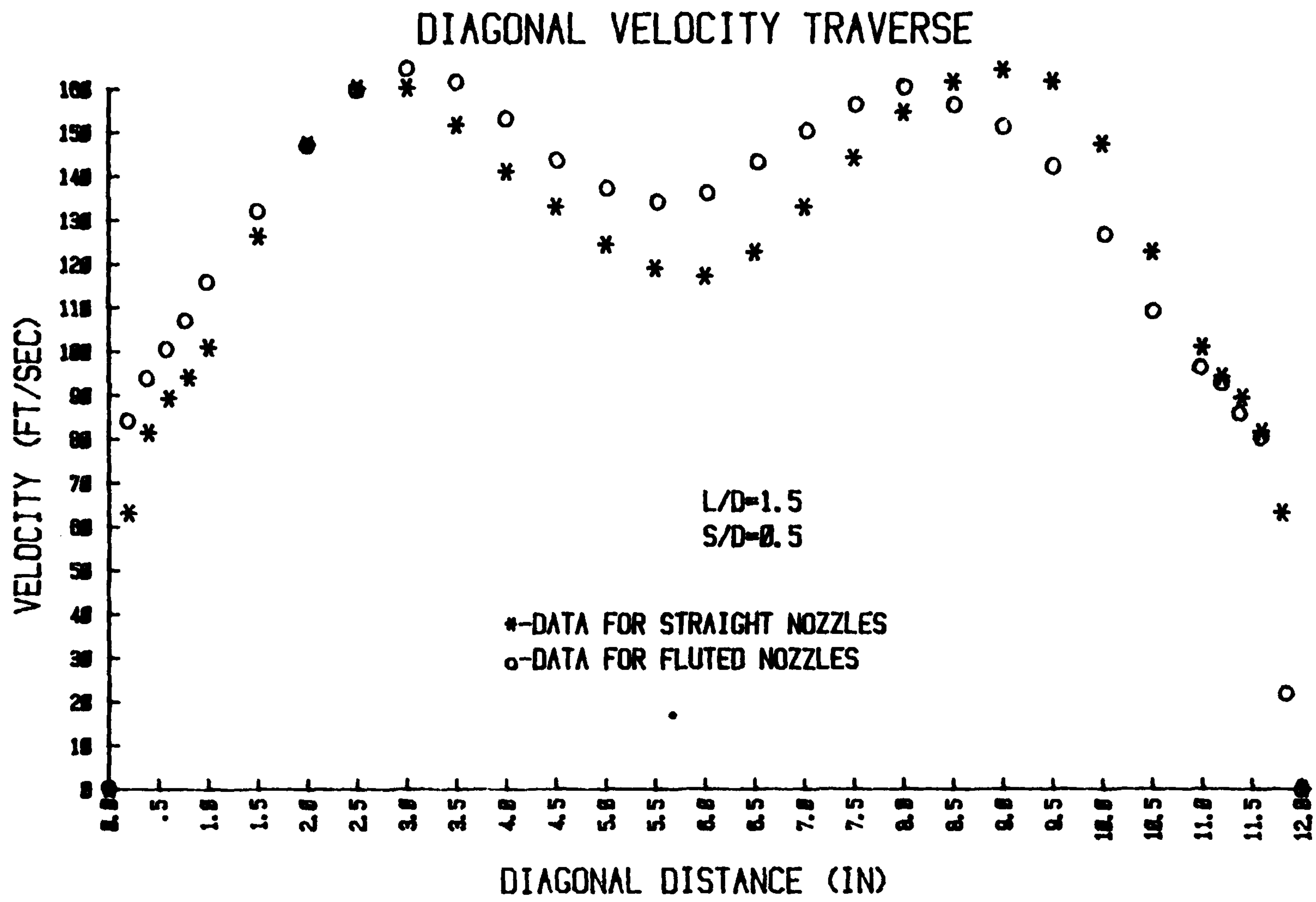

Figure 54. (contd) VTD

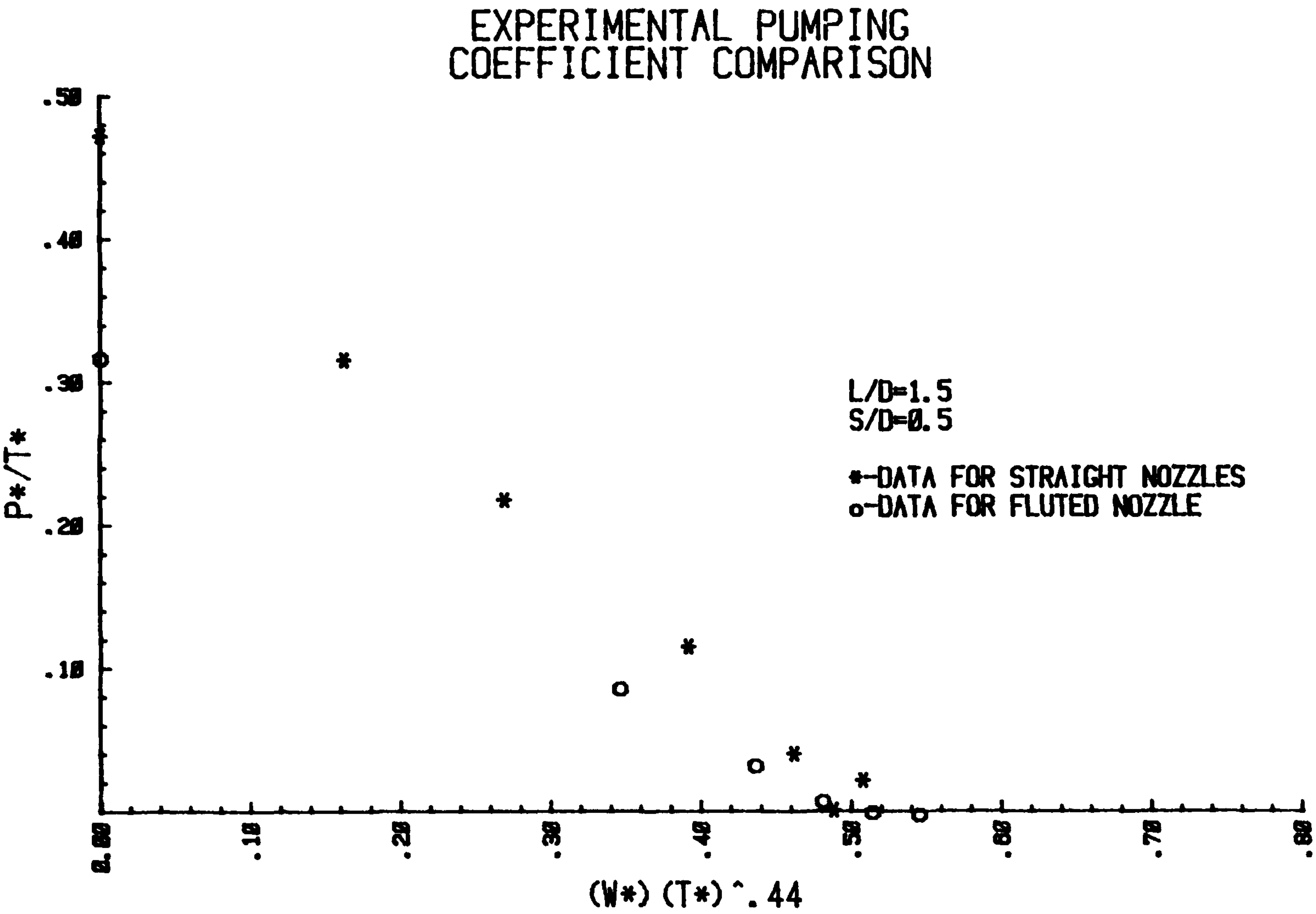

Figure 55. Straight vs Fluted (Single Nozzle)

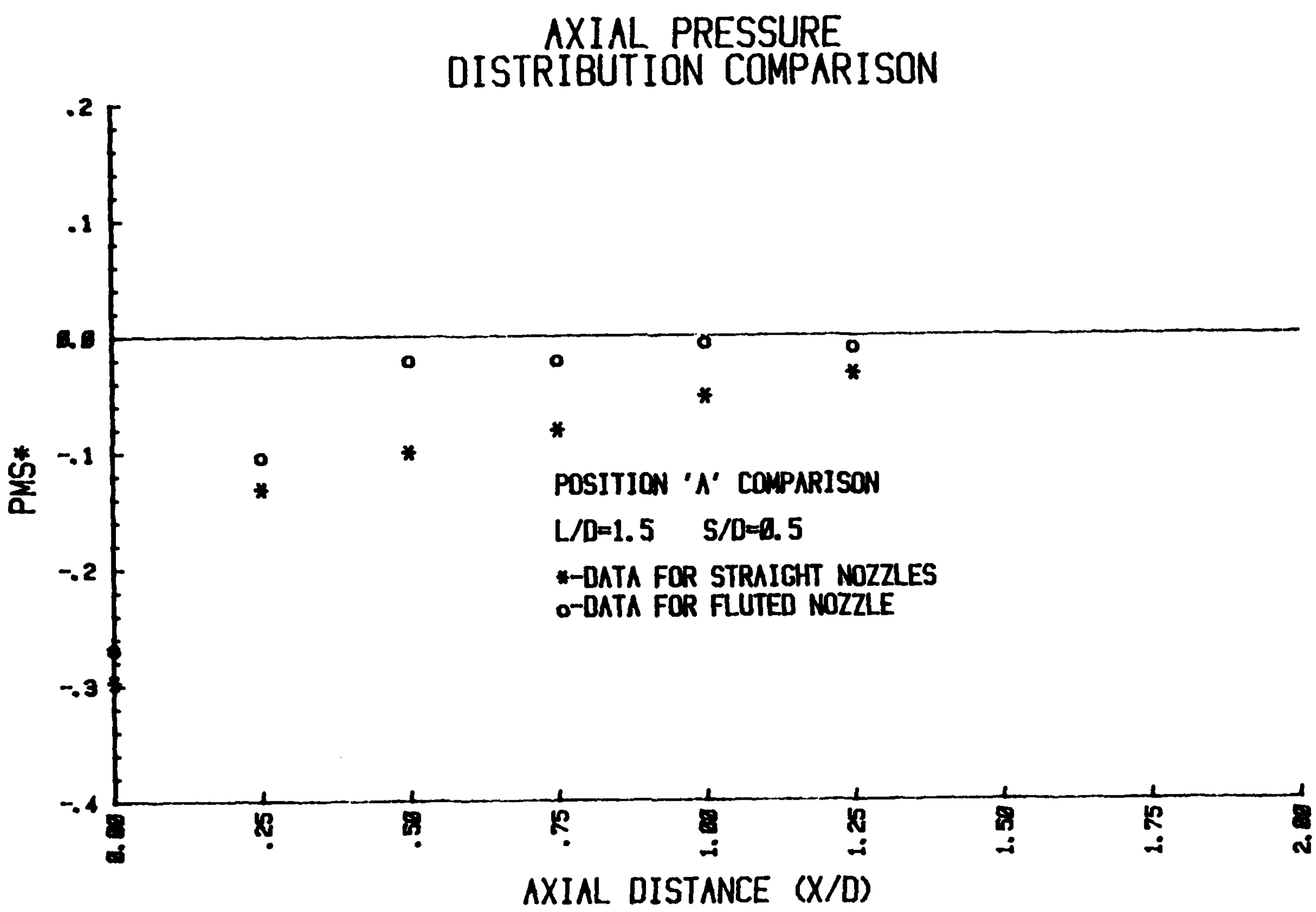

Figure 55. (contd) MSD

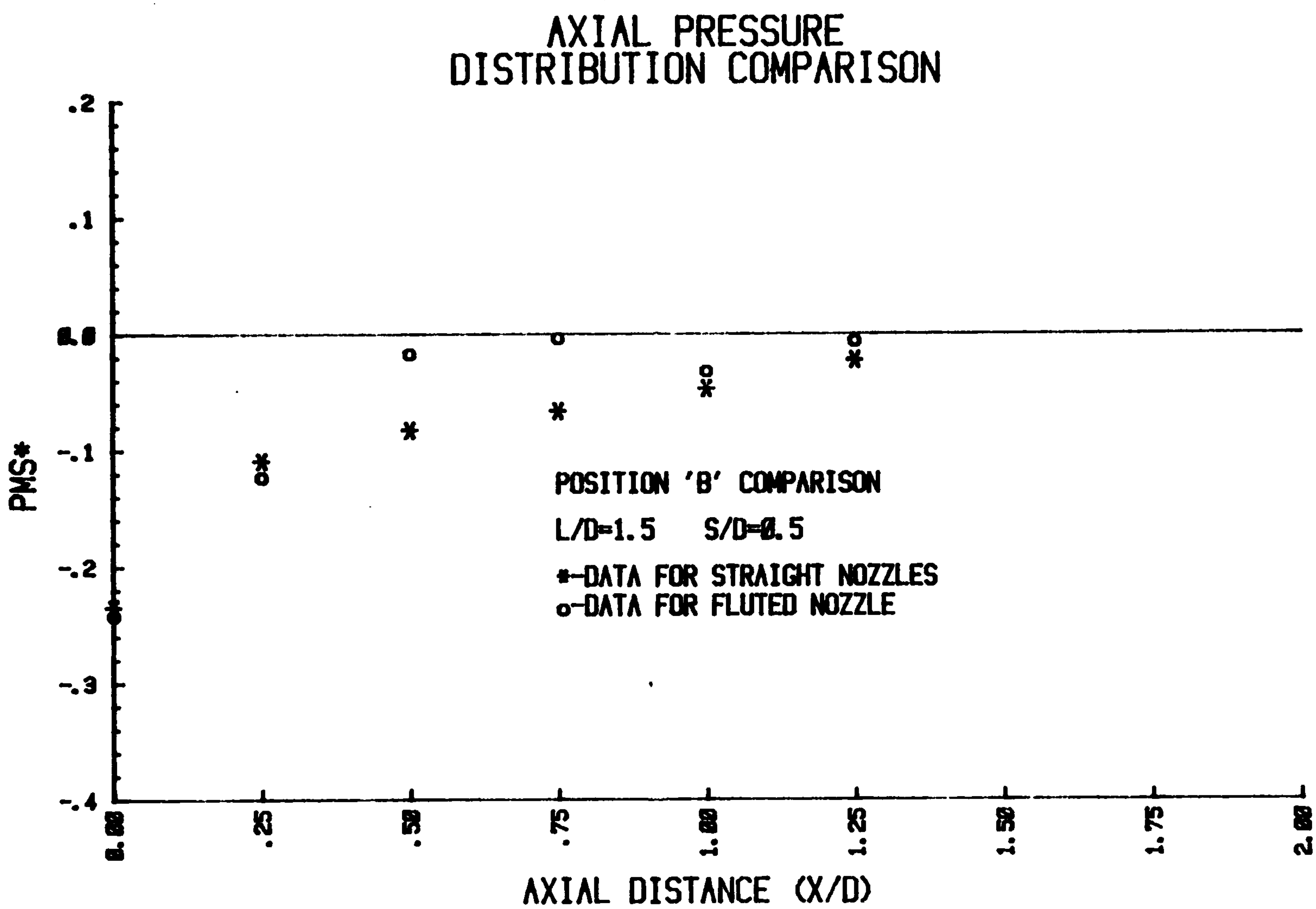

Figure 55. (contd) MSD

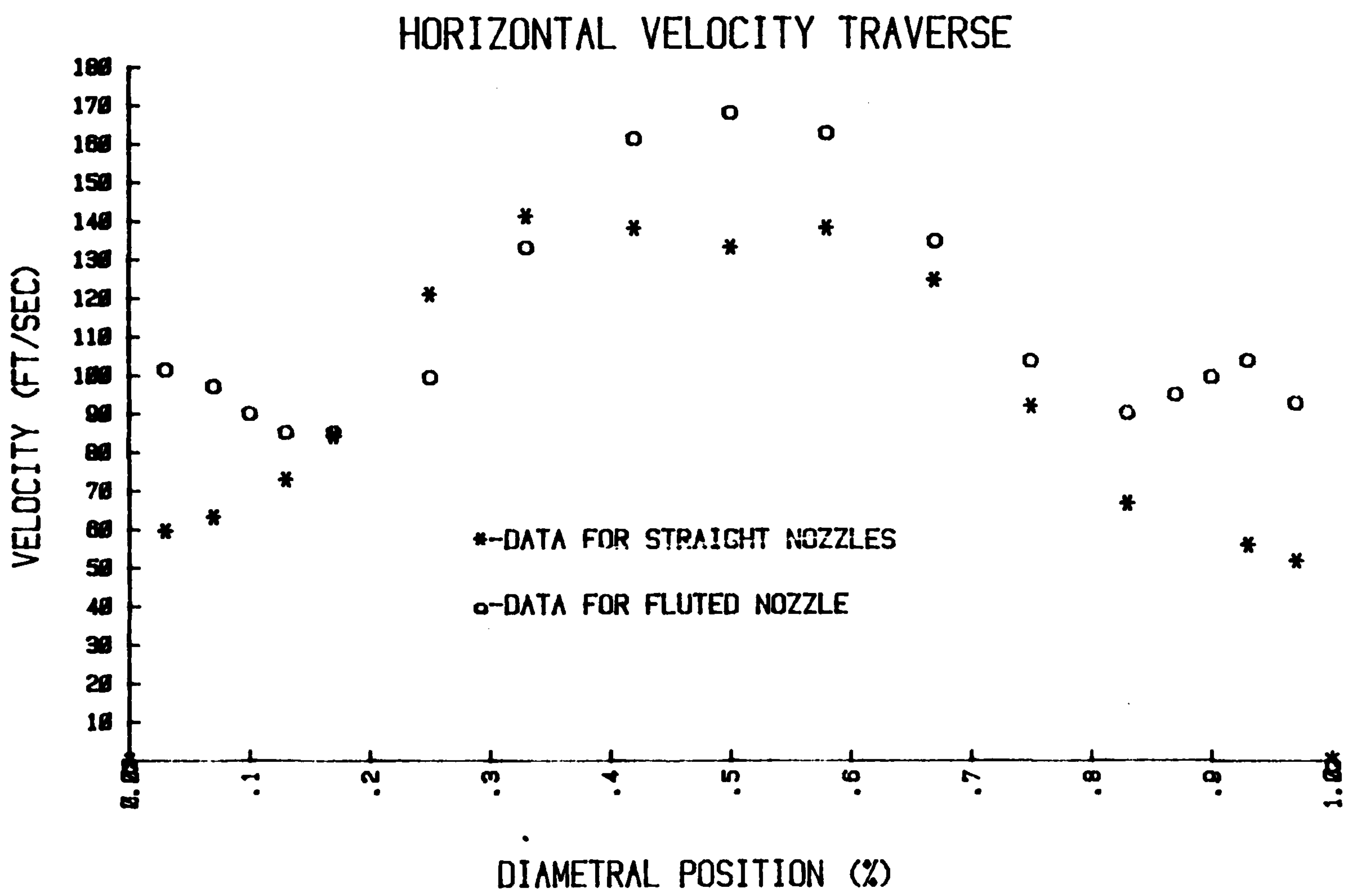

Figure 55. (contd) VTD

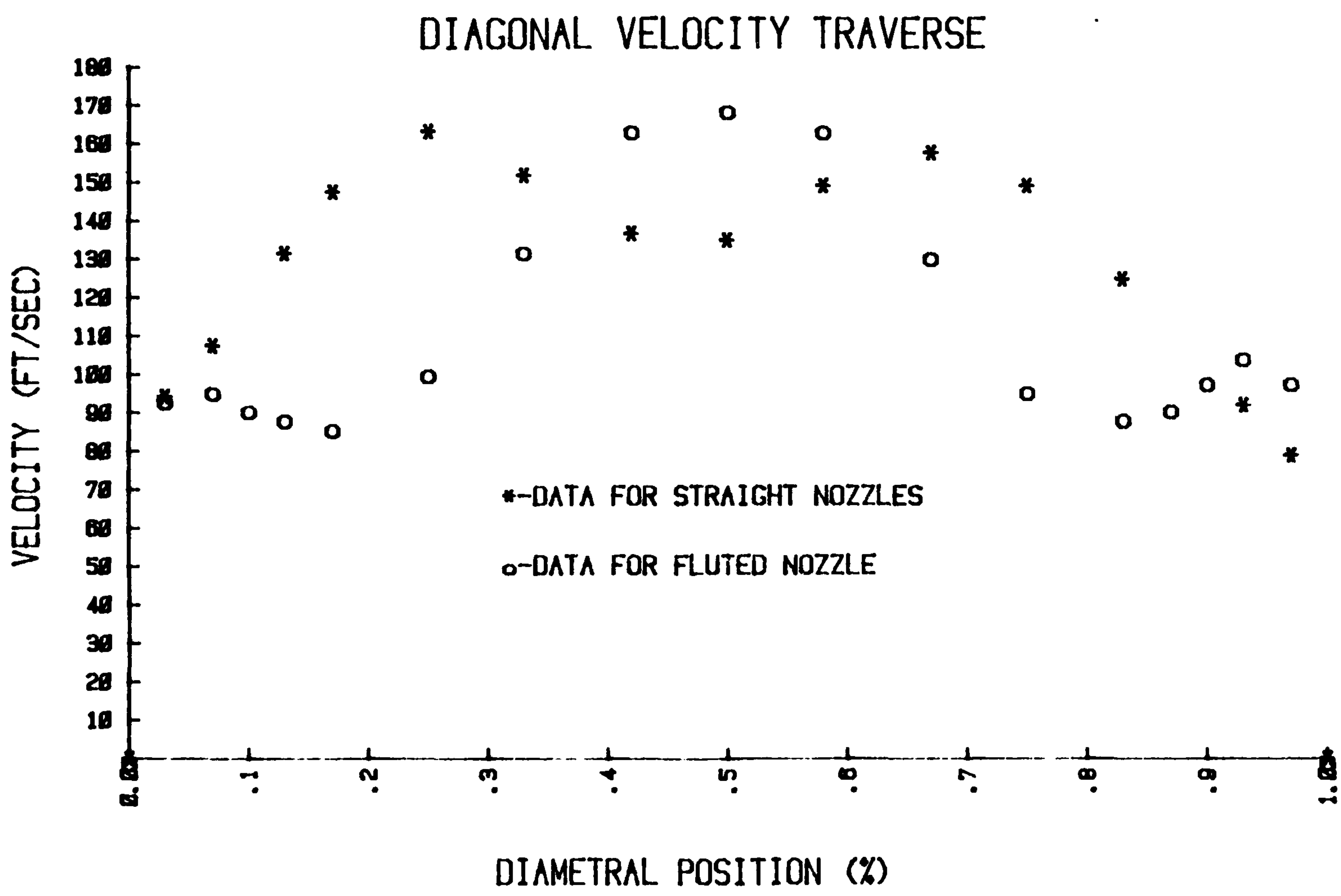

Figure 55. (contd) VTD

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11. Harrel, J. P., Jr., Experimentally Determined Effects of Eductor Geometry on the Performance of Exhaust Gas Eductors for Gas Turbine Powered Ships, Engineer's Thesis, Naval Postgraduate School, September 1977.

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APPENDIX A: FORMULAE

Presented here are the formulas used to obtain the primary and secondary mass flow rates. According to the ASME primary Test Code [Ref. 9], the general equation for mass flow rate appearing in equation (a)

$$W(\text{lbm/sec}) = (0.12705)\ K\ A\ Y\ F_a\ (\rho\ \Delta P)^{0.5} \qquad \text{(a)}$$

may be used with flow nozzles and square edge orifices provided the flow is subsonic. In the above equation, K (dimensionless) represents the flow coefficient for the metering device and is defined as $K = C(1 - \beta^4)^{-0.5}$ where C is the coefficient of discharge and β is the ratio of throat to inlet diameters; $A(\text{in}^2)$ is the total cross sectional area of the metering device; Y (dimensionless) is the expansion factor for the flow; F_a (dimensionless) is the area thermal expansion factor; ρ (lbm/ft^3) is the flow mass density; and ΔP (inches H_2O) is the differential pressure across the metering device. Each of these quantities are evaluated, according to the guidelines set forth in Reference [8], for the specific type of flow measuring device used.

Using a square edge orifice for measurement of the primary mass flow rate, the quantities in equation (a) are defined as follows:

1. The flow coefficient K is 0.62 based on a β of 0.502 and a constant coefficient of discharge over the range of flows considered of 0.60.
2. The orifice area is 37.4145 in^2.
3. Corresponding to the range of pressure ratios encountered across the orifice, the expansion factor Y is 0.98.
4. Since the temperature of the metered air is nearly ambient temperature, thermal expansion factor is essentially 1.0.
5. The primary air mass density ρ_{or} is calculated using the perfect gas relationship with pressure and temperature evaluated upstream of the orifice.

Substituting these values into equation (a) yields

$$W_p \text{ (lbm/sec)} = (2.88455)\ (\rho_{or}\Delta P_{or})^{0.5} \tag{b}$$

The secondary mass flow rate is measured using long radius flow nozzles for which case the quantities in equation (a) becomes:

1. For a flow nozzle installed in a plenum, β is approximately zero in which case the flow coefficient is approximately equal to the coefficient of discharge. For the range of secondary flows encountered, the flow coefficient becomes 0.98.
2. A is the sum of the throat areas of the flow nozzles in use (in^2).

3. Since the pressure ratios across the flow nozzles are very close to unity, the expansion coefficient Y is 1.0.
4. Since the temperature of the metered air is nearly ambient temperature, the thermal expansion factor is essentially 1.0.
5. The secondary air mass density ρ_s is evaluated using the perfect gas relationship at ambient conditions.

Substituting these values into equation (a) yields the equation for the secondary mass flow rate measured using long radius flow nozzles.

$$W_s \text{ (lbm/sec)} = (0.12451)\ A\ (\rho_s\ \Delta P_s)^{0.5} \qquad \text{(c)}$$

APPENDIX B: UNCERTAINTY ANALYSIS

The determination of the uncertainties in the experimentally determined pressure coefficients, pumping coefficients, and velocity profiles was made using the methods described by Kline and McClintock [Ref. 12]. The basic uncertainty analysis for the cold flow eductor model test facility was conducted by Ellin [Ref. 1]. The uncertainties obtained by Ellin using the second order equation suggested by Kline and McClintock were applicable to the experimental work conducted during the present research and are listed in the following table.

<u>UNCERTAINTY IN MEASURED VALUES</u>

T_s	± 1 R
T_p	± 1R
P_a	± 0.01 psia
ΔP	± 0.01 in. H_2O
P_V	± 0.01 in. H_2O
P_u	± 0.05 in. H_2O
ΔP_s(+)	± 0.01 in. H_2O
ΔP_t(**)	± 0.01 in. H_2O
P_{or}	± 0.01 in, H_2O
ΔP_{or}	± 0.20 in. H_2O
T_{or}	± 1 R

T_a	± 1 R
PT (***)	± 0.1 in. H_2O

UNCERTAINTY IN CALCULATED VALUES

$\frac{P^*}{T^*}$	1.9%
$W^*T^{*0.44}$	1.4%
V/V_{avg}	2.5%
(+)	The pressure differential across the secondary flow nozzles, P_s, is the major source of uncertainty in the pumping coefficient.
(++)	The pressure differential across the tertiary flow nozzles, P_t, is the major source of uncertainty in the pumping coefficient.
(+++)	The measurement of the total pressure for the velocity profile is the major source of uncertainty in the velocity calculation.

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